COSMOS

A Sketch of a Physical Description of the Universe

By Alexander Von Humboldt

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Alexander von Humboldt (1845)
Translated by Elise C. Otté (1866)
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THE colors are now: light blue above (**where is my cyanometer? Saussure invented one, and Humboldt used it in his travels**); landscape russet and greenish, spotted with fawn-colored plowed lands, with green pine and gray or reddish oak woods intermixed, and dark-blue or slate-colored water here and there. It is greenest in the meadows and where water has lately stood, and a strong, invigorating scent comes up from the fresh meadows. It is like the greenness of an apple faintly or dimly appearing through the russet.

—— Henry David Thoreau in his *Journal*, May 1, 1853

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Chapter 1

Introduction

1.1 Reflections on the different degrees of enjoyment presented to us by the aspect of nature and the study of her laws.

In attempting, after a long absence from my native country, to develop the physical phenomena of the globe, and the simultaneous action of the forces that pervade the regions of space, I experience a twofold cause of anxiety. The subject before me is so inexhaustible and so varied, that I fear either to fall into the superficiality of the encyclopedist, or to weary the mind of my reader by aphorisms consisting of mere generalities clothed in dry and dogmatical forms. Undue conciseness often checks the flow of expression, while diffuseness is alike detrimental to a clear and precise exposition of our ideas. Nature is a free domain, and the profound conceptions and enjoyments she awakens within us can only be vividly delineated by thought clothed in exalted forms of speech, worthy of bearing witness to the majesty and greatness of the creation.

In considering the study of physical phenomena, not merely in its bearings on the material wants of life, but in its general influence on the intellectual advancement of mankind, we find its noblest and most important result to be a knowledge of the chain of connection, by which all natural forces are linked together, and made mutually dependent upon each other; and it is the perception of these relations that exalts our views and ennobles our enjoyments. Such a result can, however, only be reaped as the fruit of observation and intellect, combined with the spirit of the age, in which are reflected all the varied phases of thought. He who can trace through bygone times, the stream of our knowledge to its primitive source, will learn from history how, for thousands of years, man has labored, amid the ever recurring changes of form, to recognize the invariability of natural laws, and has thus, by the force of mind, gradually subdued a great portion of the physical world to his dominion. In interrogating the history of the past, we trace the mysterious course of ideas yielding the first glimmering perception of the same image of a Cosmos, or harmoniously ordered whole, which, dimly shadowed forth to the human mind in the primitive ages of the world, is now fully revealed to the maturer intellect of mankind as the result of long and laborious observation.

Each of these epochs of the contemplation of the external world – the earliest dawn of thought and the advanced stage of civilization – has its own source of enjoyment. In the former, this enjoyment, in accordance with the simplicity of the primitive ages, flowed from an intuitive feeling of the order that was proclaimed by the invariable and successive reappearance of the heavenly bodies, and by the progressive development of organized beings; while in the latter, this sense of enjoyment springs from a definite knowledge of the phenomena of nature. When man began to interrogate nature, and not content with observing, learned to evoke phenomena under definite conditions; when once he sought to collect and record facts, in order that the fruit of his labors might aid investigation after his own brief existence had passed away, the philosophy of Nature cast aside the vague and poetic garb in which she had been enveloped from her origin, and, having assumed a severer aspect, she now weighs the value of observations and substitutes induction and reasoning for conjecture and assumption. The dogmas of former ages survive now only in the superstitions of the people and the prejudices of the ignorant, or are perpetuated in a few systems which, conscious of their weakness, shroud themselves in a veil of mystery. We may also trace the same primitive intuitions in languages exuberant in figurative expressions; and a few of the best chosen symbols engendered by the happy inspiration of the earliest ages, having by degrees lost their vagueness through a better mode of interpretation, are still preserved among our scientific terms.

Nature considered rationally, that is to say, submitted to the process of thought, is a unity in diversity of phenomena; a harmony, blending together all created things; however dissimilar in form and attributes; one great whole (76 7v) animated by the breath of life. The most important result of a rational inquiry into nature is, therefore, to establish the unity and harmony of this stupendous mass of force and matter, to determine with impartial justice what is due to the discoveries of the past and to those of the present, and to analyze the individual parts of natural phenomena without succumbing beneath the weight of the whole. Thus, and thus alone, is it permitted to man, while mindful of the high destiny of his race, to comprehend nature, to lift the veil that shrouds her phenomena, and, as it were, submit the results of observation to the test of reason and of intellect.

In reflecting upon the different degrees of enjoyment presented to us in the contemplation of nature, we find that the first place must be assigned to a sensation, which is wholly independent of an intimate acquaintance with the physical phenomena presented to our view, or of the peculiar character of the region surrounding us. In the uniform plain bounded only by a distant horizon, where the lowly heather, the cistus, or waving grasses, deck the soil; on the ocean shore, where the waves, softly rippling over the beach, leave a track, green with the weeds of the sea; everywhere, the mind is penetrated by the same sense of the grandeur and vast expanse of nature, revealing to the soul, by a mysterious inspiration, the existence of laws that regulate the forces of the universe. Mere communion with nature, mere contact with the free air, exercise a soothing yet strengthening influence on the wearied spirit, calm the storm of passion, and soften the heart when shaken by sorrow to its inmost depths. Everywhere, in every region of the globe, in every stage of intellectual culture, the same sources of enjoyment are alike vouchsafed to man. The earnest and solemn thoughts awakened by a communion with nature intuitively arise from a presentiment of the order and harmony pervading the whole universe, and from the contrast we draw between the narrow limits of our own existence and the image of infinity revealed on every side, whether we look upward to the starry vault of heaven, scan the far-stretching plain before us, or seek to trace the dim horizon across the vast expanse of ocean.

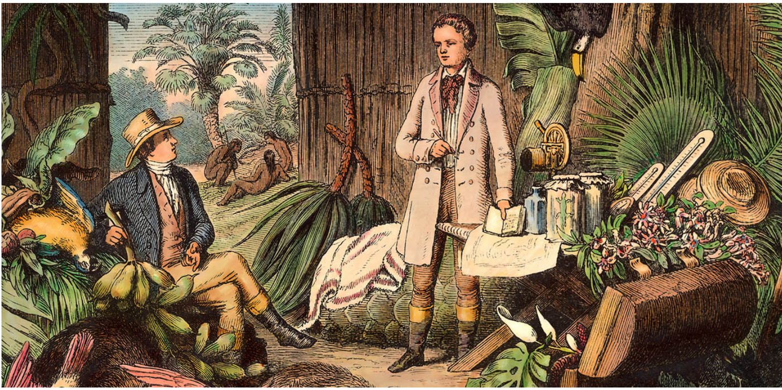

Figure 1.1: Alexander von Humboldt & Aimé Bonpland, Orinocco – Woodcut (1870) of Otto Roth from a drawing by H. Lademann. Image in the public domain.

The contemplation of the individual characteristics of the landscape, and of the conformation of the land in any definite region of the earth, gives rise to a different source of enjoyment, awakening impressions that are more vivid, better defined, and more congenial to certain phases of the mind, than those of which we have already spoken. At one time the heart is stirred by a sense of the grandeur of the face of nature, by the strife of the elements, or, as in Northern Asia, by the aspect of the dreary barrenness of the far-stretching steppes; at another time, softer emotions are excited by the contemplation of rich harvests wrested by the hand of man from the wild fertility of nature, or by the sight of human habitations raised beside some wild and foaming torrent. Here I regard less the degree of intensity than the difference existing in the various sensations that derive their charm and permanence from the peculiar character of the scene.

If I might be allowed to abandon myself to the recollections of my own distant travels, I would instance, among the most striking scenes of nature, the calm sublimity of a tropical night, when the stars, not sparkling, as in our northern skies, shed their soft and planetary light over the gently heaving ocean; or I would recall the deep valleys of the Cordilleras, where the tall and slender palms pierce the leafy veil around them, and waving on high their feathery and arrowlike branches, form, as it were, a "forest above a forest"[1]; or I would describe the summit of the Peak of Teneriffe, when a horizontal layer of clouds, dazzling in whiteness, has separated the cone of cinders from the plain below, and suddenly the ascending current pierces the cloudy veil, so that the eye of the traveler may range from the brink

[1]This expression is taken from a beautiful description of tropical forest scenery in *Paul and Virginia*, by Bernardin de Saint Pierre.

of the crater, along the vineclad slopes of Orotava, to the orange gardens and banana groves that skirt the shore. In scenes like these, it is not the peaceful charm uniformly spread over the face of nature that moves the heart, but rather the peculiar physiognomy and conformation of the land, the features of the landscape, the ever-varying outline of the clouds, and their blending with the horizon of the sea, whether it lies spread before us like a smooth and shining mirror, or is dimly seen through the morning mist. All that the senses can but imperfectly comprehend, all that is most awful in such romantic scenes of nature, may become a source of enjoyment to man, by opening a wide field to the creative powers of his imagination. Impressions change with the varying movements of the mind, and we are led by a happy illusion to believe that we receive from the external world that with which we have ourselves invested it.

When far from our native country, after a long voyage, we read for the first time the soil of a tropical land, we experience a certain feeling of surprise and gratification in recognizing, in the rocks that surround us, the same inclined schistose strata, and the same columnar basalt covered with cellular amygdaloids, that we had left in Europe, and whose identity of character, in latitudes so widely different, reminds us that the solidification of the earth's crust is altogether independent of climatic influences. But these rocky masses of schist and of basalt are covered with vegetation of a character with which we are unacquainted, and of a physiognomy wholly unknown to us; and it is then, amid the colossal and majestic forms of an exotic flora, that we feel how wonderfully the flexibility of our nature fits us to receive new impressions, linked together by a certain secret analogy. We so readily perceive the affinity existing among all the forms of organic life, that although the sight of a vegetation similar to that of our native country might at first be most welcome to the eye, as the sweet familiar sounds of our mother tongue are to the ear, we nevertheless, by degrees, and almost imperceptibly, become familiarized with a new home and a new climate. As a true citizen of the world, man everywhere habituates himself to that which surrounds him; yet fearful, as it were, of breaking the links of association that bind him to the home of his childhood, the colonist applies to some few plants in a far distant clime the names he had been familiar with in his native land; and by the mysterious relations existing among all types of organization, the forms of exotic vegetation present themselves to his mind as nobler and more perfect developments of those he had loved in earlier days. Thus do the spontaneous impressions of the untutored mind lead, like the laborious deductions of cultivated intellect, to the same intimate persuasion, that one sole and indissoluble chain binds together all nature.

It may seem a rash attempt to endeavor to separate, into its different elements, the magic power exercised upon our minds by the physical world, since the character of the landscape, and of every imposing scene in nature, depends so materially upon the mutual relation of the ideas and sentiments simultaneously excited in the mind of the observer.

The powerful effect exercised by nature springs, as it were, from the connection and unity of the impressions and emotions produced; and we can only trace their different sources by analyzing the individuality of objects and the diversity of forces.

The richest and most varied elements for pursuing an analysis of this nature present themselves to the eyes of the traveler in the scenery of Southern Asia, in the Great Indian Archipelago, and more especially, too, in the New Continent, where the summits of the lofty Cordilleras penetrate the confines of the aerial ocean surrounding our globe, and where the same subterranean forces that once raised these mountain chains still shake them to their foundation and threaten their downfall.

Graphic delineations of nature, arranged according to systematic views, are not only suited to please the imagination, but may also, when properly considered, indicate the grades of the impressions of which I have spoken, from the uniformity of the seashore, or the barren steppes of Siberia, to the inexhaustible fertility of the torrid zone. If we were even to picture to ourselves Mount Pilatus placed on the Schreckhorn [2], or the Schneekoppe of Sile-

[2]These comparisons are only approximative. The several elevations above the level of the sea are, in accurate numbers, as follows: The Schneekoppe or Riesenkoppe, in Silesia, about 5270 feet, according to Hallaschka. The Righi, 5902 feet, taking the height of the Lake of Lucerne at 1426 feet, according to Eschman. Mount Athos, 6775 feet, according to Captain Gaultier; Mount Pilatus, 7546 feet; Mount Ætna, 10,871 feet, according to Captain Smyth; or 10,874 feet, according to the barometrical measurement made by Sir John Herschel, and communicated to me in writing in 1825, and 10,899 feet, according to angles of altitude taken by Cacciatore at Palermo (calculated by assuming the terrestrial refraction to be 0.076); the Schreckhorn, 12,383 feet; the Jungfrau, 13,720 feet, according to Tralles; Mont Blanc, 15,775 feet, according to the different measurements considered by Roger (Bibl. Univ., May, 1828, p. 2453), 15,733 feet, according to the measurements taken from Mount Columbier by Carlini in

1821, and 15,748 feet, as measured by the Austrian engineers from Trelod and the Glacier d'Ambin.

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The actual height of the Swiss mountains fluctuates, according to Eschman's observations, as much as 25 English feet, owing to the varying thickness of the stratum of snow that covers the summits. Chimborazo is, according to my trigonometrical measurements, 21,421 feet (see Humboldt, Recueil d'Obs. Astr., tome i., p. 73), and Dhawalagiri, 28,074 feet. As there is a difference of 445 feet between the determinations of Blake and Webb, the elevation assigned to the Dhawalagiri (or white mountain, from the Sanskrit dhawala, white, and gi7i, mountain) can not be received with the same confidence as that of the Jawahir, 25,749 feet, since the latter rests on a complete trigonometrical measurement (see Herbert and Hodgson in the Aséat. Res., vol. xiv., p. 189, and Suppl. to Encycl. Brit., vol. iv., p. 643). I have shown elsewhere (Ann. des Sciences Naturelles, Mars, 1825) that the height of the Dhawalagiri (28,074 feet) depends on several elements that have not been ascertained with certainty, such as azimuths and latitudes (Humboldt, Asie Centrale, t. iii., p. 282). It has been believed, but without foundation, that in the Tartaric chain, north of Thibet, opposite to the chain of Kuenlun, there are several snowy summits, whose elevation is about 30,000 English feet (almost twice that of Mont Blanc), or, at any rate, 29,000 feet (see Captain Alexander Gerard's and John Gerard's Journey to the Boorendo Pass, 1840, vol. i., p. 143 and 311). Chimborazo is spoken of in the text only as one of the highest summits of the chain of the Andes; for in the year 1827, the learned and highly gifted traveler, Pentland, in his memorable expedition to Upper Peru (Bolivia), measured the elevation of two mountains situated to the east of Lake Titicaca, viz., the Sorata, 25,200 feet, and the Illimani, 24,000 feet, both greatly exceeding the height of Chimborazo, which is only 21,421 feet, and being nearly equal in elevation to the Jawahir, which is the highest mountain in the Himalaya that has as yet been accurately measured.

Thus Mont Blanc is 5646 feet below Chimborazo; Chimborazo, 3779 feet below the Sorata; the Sorata, 549 feet below the Jawahir, and probably about 2880 feet below the Dhawalagiri. According to a new measurement of the Illimani, by Pentland, in 1838, the elevation of this mountain is given at 23,868 feet, varying only 133 feet from the measurement taken in 1827. The elevations have been given in this note with minute exactness, as erroneous numbers have been sia on Mont Blanc, we should not have attained to the height of that great Colossus of the Andes, the Chimborazo, whose height is twice that of Mount Ætna; and we must pile the Righi, or Mount Athos, on the summit of the Chimborazo, in order to form a just estimate of the elevation of the Dhawalagiri, the highest point of the Himalaya. But although the mountains of India greatly surpass the Cordilleras of South America by their astonishing elevation (which, after being long contested, has at last been confirmed by accurate measurements), they cannot, from their geographical position, present the same

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introduced into many maps and tables recently published, owing to incorrect redactions of the measurements.

[In the preceding note, taken from those appended to the Introduction in the French translation, rewritten by Humboldt himself, the measurements are given in meters, but these have been converted into English feet, for the greater convenience of the general reader.] – Tr.

inexhaustible variety of phenomena by which the latter are characterized. The impression produced by the grander aspects of nature does not depend exclusively on height. The chain of the Himalaya is placed far beyond the limits of the torrid zone, and scarcely a solitary palm tree is to be found in the beautiful valleys of Kumaoun and Garhwal[3]. On the southern slope of the ancient Paropamisus, in the latitudes of 28 and 34, nature no longer displays the same abundance of tree ferns and arborescent grasses, heliconias and orchidaceous plants, which in tropical regions are to be found even on the highest

[3]The absence of palms and tree ferns on the temperate slopes of the Himalaya is shown in Don's Flora Nepalensis, 1825, and in the remarkable series of lithographs of Wallich's Flora Indica, whose catalogue contains the enormous number of 7683 Himalaya species, almost all phanerogamic plants, which have as yet been but imperfectly classified. In Nepal (lat. 26° to 27°) there has hitherto been observed only one species of palm, Chamerops martiana, Wall. (Plante Asiat., lib. iii., p. 5, 211), which is found at the height of 5250 English feet above the level of the sea, in the shady valley of Bunipa. The magnificent tree fern Alsophila brunoniana, Wall. (of which a stem 48 feet long has been in the possession of the British Museum since 1831), does not grow in Nepal, but is found on the mountains of Silhet, to the northwest of Calcutta, in lat. 24° 9′. The Nepal fern, Paranema cyathiodes, Don, formerly known as Spheroptera barbata, Wall. (Plante Asiat., lib. i., p. 42, 48), is indeed nearly related to Cyathea, a species of which we saw in the South American Missions of Caripe, measuring 33 feet in height; this is not, however, properly speaking, a tree.

plateaux of the mountains. On the slope of the Himalaya, under the shade of the Deodora and the broadleaved oak, peculiar to these Indian Alps, the rocks of granite and of mica schist are covered with vegetable forms almost similar to those which characterize Europe and Northern Asia. The species are not identical, but closely analogous in aspect and physiognomy, as, for instance, the juniper, the alpine birch, the gentian, the marsh parnassia, and the prickly species of Ribes[4]. The chain of the

[4]Ribes nubicola, R. glaciale, R. grossularia. The species which compose the vegetation of the Himalaya are four pines, notwithstanding the assertion of the ancients regarding Eastern Asia (Strabo, lib. 11, p. 510, Cas.), twenty-five oaks, four birches, two chestnuts, seven maples, twelve willows, fourteen roses, three species of strawberry, seven species of Alpine roses (rhododendra), one of which attains a height of 20 feet, and many other northern genera. Large white apes, having black faces, inhabit the wild chestnut tree of Kashmir, which grows to a height of 100 feet, in lat. 33 (see Carl von Hiigels Kaschmir, 1840, 2d pt. 249). Among the Conifer, we find the Pinus deodwara, or deodara (in

Himalaya is also wanting in the imposing phenomena of volcanoes, which in the Andes and in the Indian Archipelago often reveal to the inhabitants, under the most terrific forms, the existence of the forces pervading the interior of our planet.

Moreover, on the southern declivity of

Sanscrit, déwadaru, the timber of the gods), which is nearly allied to Pinus cedrus. Near the limit of perpetual snow flourish the large and showy flowers of the Gentiana venusta, G. Moorcroftiana, Swertia purpurescens, S. speciosa, Parnassia armata, P. nubicola, Poeonia Emodi, Tulipa stellata; and, besides varieties of European genera peculiar to these Indian mountains, true European species, as Leontodon taraxacum, Prunella vulgaris, Galium aparine, and Thlaspi arvense. The heath mentioned by Saunders, in Turner's Travels, and which had been confounded with Calluna vulgaris, is an Andromeda, a fact of the greatest importance in the geography of Asiatic plants. If I have made use, in this work, of the unphilosophical expressions of European genera, European species, growing wild in Asia, c., it has been in consequence of the old botanical language, which, instead of the idea of a large dissemination, or, rather, of the coexistence of organic productions, has dogmatically substituted the false hypothesis of a migration, which, from predilection for Europe, is further assumed to have been from west to east.

the Himalaya, wherethe ascending current deposits the exhalations rising from avigorous Indian vegetation, the region of perpetual snow begins at an elevation of 11,000 or 12,000 feet above the levelof the sea,[5] thus setting a limit to the develop-

[5]On the southern declivity of the Himalaya, the limit of perpetual snow is 12,978 feet above the level of the sea; on the northern declivity, or, rather, on the peaks which rise above the Thibet, or Tartarian plateau, this limit is at 16,625 feet from 30 to 32 of latitude, while at the equator, in the Andes of Quito, it is 15,790 feet. Such is the result I have deduced from the combination of numerous data furnished by Webb, Gerard, Herbert, and Moorcroft. (See my two memoirs on the mountains of India, in 1816 and 1820, in the Ann. de Chimie et de Physique, t. iii., p. 303; t. xiv., p. 6, 22, 50.) The greater elevation to which the limit of perpetual snow recedes on the Tartarian declivity is owing to the radiation of heat from the neighboring elevated plains, to the purity of the atmosphere, and to the infrequent formation of snow in an air which is both very cold and very dry. (Humboldt, Asie Centrale, t. iii., p. 281-326.) My opinion on the difference of height of the snowline on the two sides of the Himalaya has the high authority of Colebrooke in its favor. He wrote to me in June, 1824, as follows: "I also find, from the data in my possession, that the elevation of the line of perpetual snow is 13,000 feet. On the southern declivity, and at latitude 31, Webb's

measurements give me 13,500 feet, consequently 500 feet more than the height deduced from Captain Hedgson's observations. Gerard's measurements fully confirm your opinion that the line of snow is higher on the northern than on the southern side." It was not until the present year (1840) that we obtained the complete and collected journal of the brothers Gerard, published under the supervision of Mr. Lloyd. (Narrative of a Journey from Cawnpoor to the Boorendo Pass, in the Himalaya, by Captain Alexander Gerard and John Gerard, edited by George Lloyd, vol. i., p. 291, 311, 320, 327, and 341.) Many interesting details regarding some localities may be found in the narrative of A Visit to the Shatool, for the Purpose of determining the Line of Perpetual Snow on the southern face of the Himalaya, in August, 1822. Unfortunately, however, these travelers always confound the elevation at which sporadic snow falls with the maximum of the height that the snowline attains on the Thibetian plateau. Captain Gerard distinguishes between the summits that rise in the middle of the plateau, where he states the elevation of the snowline to be between 18,000 and 19,000 feet, and the northern slopes of the chain of the Himalaya, which border on the defile of the Sutledge, and can radiate but little heat, owing to the deep ravines with which they are intersected. The elevation of the village of Tangno is given at only 1300 feet, while that of the plateau surrounding the lake of Minasa is 17,000 feet. Captain Gerard finds the snowline 500 feet lower on the northern slopes, where the chain of the Himalaya is broken through, than toward the southern declivities facing Hindostan, and he there estimates the line of perpetual snow at 15,000 feet. The most striking differences are presented between the vegetation on the Thibetian plateau and that characteristic of the southern slopes of the Himalaya. On the latter, the cultivation of grain is arrested at 9974 feet, and even there the corn has often to be cut when the blades are still green. The extreme limit of forests of tall oaks and deodars is 11,960 feet; that of dwarf birches, 12,983 feet. On the plains, Captain Gerard found pastures up to the height of 17,000 feet; the cereals will grow at 14,100 feet, or even at 18,540 feet; birches with tall stems at 14,100 feet, and copse or brushwood applicable for fuel is found at an elevation of an of 17,000 feet, that is to say, 1280 feet above the lower limits of the snowline at the equator, in the province of Quito. It is very desirable that the mean elevation of the Thibetian plateau, which I have estimated at only about 8200 feet between the Himalaya and the Kuenlun, and the difference in the height of the line of perpetual snow on the southern and on the northern slopes of the Himalaya, should be again investigated by travelers who are accustomed to judge of the general conformation of the land. Hitherto simple calculations have too often been confounded with actual measurements, and the elevations of isolated summits with that of the surrounding plateau. (Compare Carl Zimmerman's excellent Hypsometrical Remarks in his Geographischen Analyse der Karte von Inner Asien, 1841, s. 98.) Lord draws attention to the difference presented by the two faces of the Himalaya and those of the Alpine chain of HindooCoosh, with respect to the limits of the snowline. The latter chain, he says, has the tableland to the south, in consequence of which the snowline is higher on the southern side, contrary to what we find to be the case with respect to the Himalaya, which is bounded on the south by sheltered plains, as HindooCoosh is on the north. It must, however, be admitted that the hypsometrical data on which these statements are based require a critical revision with regard to several of their details; but still they suffice to establish the main fact, that the remarkable configuration of the land in Central Asia affords man all that is essential to the maintenance of life, as habitation, food, and fuel, at an elevation above the level of the sea which in almost all other parts of the globe is covered with perpetual ice. We must except the very dry districts of Bolivia, where snow is so rarely met with, and where Pentland (in 1838) fixed the snowline at 15,667 feet, between 16 and 17° south latitude. The opinion that I had advanced regarding the difference in the snowline on the two faces of the Himalaya has been most fully confirmed by the barometrical observations of Victor Jacquemont, who fell an early sacrifice to his noble and unwearied ardor. (See his Correspondance pendant son Voyage dans l'Inde, 1828-1832, liv. 23, p. 290, 296, 299.) Perpetual snow, says Jacquemont, descends lower on the southern than on the northern slopes of the Himalaya, and the limit constantly rises as we advance to the north of the chain bordering on India. On the Kioubrong, about 18,317 feet in elevation, according to Captain Gerard, I was still considerably below the limit of perpetual snow which I believe to be 19,690 feet in this part of Hindostan. (This estimate I consider much too high.)

The same traveler says, 'To whatever height we rise on the southern declivity of the Himalaya, the climate retains the same character, and the same division of the seasons as in the plains of India; the summer solstice being every year marked by the same prevalence of rain, which continues to fall without intermission until the autumnal equinox. But a new, a totally different climate begins at Kashmir, whose elevation I estimate to be 5350 feet, nearly equal to that of the cities of Mexico and Popayan (Correspond. de Jacquemont, t. ii., p.

ment of organic life in a zone that is nearly 3000 feet lower than that to whickit attains in the equinoctial region of the Cordilleras.

But the countries bordering on the equator possess anotheradvantage, to which sufficient attention has not hitherte been directed. This portion of the surface of the globe affords inthe smallest space the greatest possible variety of impressionsfrom the contemplation of nature. Among the colossal mountains of Cundinamarea, of Quito, and of Peru, furrowed bdeep ravines, man is enabled to contem-

58 et 74). The warm and humid air of the sea, as Leopold von Buch well observes, is carried by the monsoons across the plains of India to the skirts of the Himalaya, which arrest its course, and hinder it from diverging to the Thibetian districts of Ladak and Lassa. Carl von Hügel estimates the elevation of the Valley of Kashmir above the level of the sea at 5818 feet, and bases his observation on the determination of the boiling point of water (see their 11, s. 155, and Journal of Geog. Soc., vol. vi., p. 215). In this valley, where the atmosphere is scarcely ever agitated by storms, and in 34° 7′ lat., snow is found, several feet in thickness, from December to March.

plate alike all the families of plants, and all the stars of the firmament. There, ata single glance, the eye surveys majestic palms, humid forestsof bambusa, and the varied species of Musacew, while abovethese forms of tropical vegetation appear oaks, medlars, thesweetbrier, and umbelliferous plants, as in our Europeanhomes. There, as the traveler turns his eyes to the vault ofheaven, a single glance embraces the constellation of the Southern Cross, the Magellanic clouds, and the guiding stars of theconstellation of the Bear, as they circle round the arctic pole.There the depths of the earth and the vaults of heaven dis play all the richness of their forms and the variety of theirphenomena. There the different climates are ranged the oneabove the other, stage by stage, like the vegetable zones, whosesuccession they limit; and there the observer may readilytrace the laws that regulate the diminution of heat, as theystand indelibly inscribed on the rocky walls and abrupt declivities of the Cordilleras.

Not to weary the reader with the details of the phenomena which I long since endeavored graphically to represent,[6] will

[6]See, generally, my Essai sur la Géographie des Plantes, et le Tableau physique des Régions Equinoziales, 1807, p. 80-88. On the diurnal and nocturnal variations of temperature, see Plate 9 of my Atlas Géogr. et Phys. du Nouveau Continent; and the Tables in my work, entitled De distributione Geographica Plantarum, secundum cali temperiem, et altitudinem Montium, 1817, p. 90-116; the meteorological portion of my Asie Centrale, t. iii., p. 212, 224; and, finally, the more recent and far more exact exposition of the variations of temperature experienced in correspondence with the increase of altitude on the chain of the Andes, given in Boussingault's Memoir, Sur la profondeur à laquelle on trouve, sous les Tropiques, la couche de Temperature Invariable. (Ann. de Chimie et de Physique, 1833, t. liii., p. 225-247.) This treatise contains the elevations of 128 points, included between the level of the sea and the declivity of the Antisana (17,900 feet), as well as the mean temperature of the atmosphere, which varies with the height between 81 and 35 F.

here limit myself to the consideration of a few of the general results whose combination constitutes the physical delineation of the torrid zone. That which, in the vagueness of our impressions, loses all distinctness of form, like some distant mountain shrouded from view by a veil of mist, is clearly revealed by the light of mind, which, by its scrutiny into the causes of phenomena, learns to resolve and analyze their different elements, assigning to each its individual character.

The regions of the torrid zone not only give rise to the most powerful impressions by their organic richness and their abundant fertility, but they likewise afford the inestimable advantage of revealing to man, by the uniformity of the variations of the atmosphere and the development of vital forces, and by the contrasts of climate and vegetation exhibited at different elevations, the invariability of the laws that regulate the course of the heavenly bodies, reflected, as it were, in terrestrial phenomena. Let us dwell, then, for a few moments, on the proofs of this regularity, which is such that it may be submitted to numerical calculation and computation.

In the burning plains that rise but little above the level of the sea, reign the families of the banana, the cycas, and the palm, of which the number of species comprised in the flora of tropical regions has been so wonderfully increased in the present day by the zeal of botanical travelers. To these groups succeed, in the Alpine valleys, and the humid and shaded clefts on the slopes of the Cordilleras, the tree ferns, whose thick cylindrical trunks and delicate lace-like foliage stand out in bold relief against the azure of the sky, and the cinchona, from which we derive the febrifuge bark. The medicinal strength of this bark is said to increase in proportion to the degree of moisture imparted to the foliage of the tree by the light mists which form the upper surface of the clouds resting over the plains. Everywhere around, the confines of the forest are encircled by broad bands of social plants, as the delicate aralia, the thibaudia, and the myrtle-leaved Andromeda, while the Alpine rose, the magnificent befaria, weaves a purple girdle round the spiry peaks. In the cold regions of the Paramos, which is continually exposed to the fury of storms and winds, we find that flowering shrubs and herbaceous plants, bearing large and variegated blossoms, have given place to monocotyledons, whose slender spikes constitute the sole covering of the soil. This is the zone of the grasses, one vast savannah extending over the immense mountain plateaux, and reflecting a yellow, almost golden tinge, to the slopes of the Cordilleras, on which graze the lama and the cattle domesticated by the European colonist. Where the naked trachyte rock pierces the grassy turf, and penetrates into those higher strata of air which are supposed to be less charged with carbonic acid, we meet only with plants of an inferior organization, as lichens, lecideas, and the brightly-colored, dust-like lepraria, scattered around in circular patches. Islets of fresh-fallen snow, varying in form and extent, arrest the last feeble traces of vegetable development, and to these succeeds the region of perpetual snow, whose elevation undergoes but little change, and may be easily determined. It is but rarely that the elastic forces at work within the interior of our globe have succeeded in breaking through the spiral domes, which, resplendent in the brightness of eternal snow, crown the summits of the Cordilleras; and even where these subterranean forces have opened a permanent communication with the atmosphere, through circular craters or long fissures, they rarely send forth currents of lava, but merely eject ignited scoriae, steam, sulphureted hydrogen gas, and jets of carbonic acid. In the earliest stages of civilization, the grand and imposing spectacle presented to the minds of the inhabitants of the tropics could only awaken feelings of astonishment and awe. It might, perhaps, be supposed, as we have already said, that the periodical return of the same phenomena, and the uniform manner in which they arrange themselves in successive groups, would have enabled man more readily to attain to a knowledge of the laws of nature; but, as far as tradition and history guide us, we do not find that any application was made of the advantages presented by these favored regions. Recent researches have rendered it very doubtful whether the primitive seat of Hindoo civilization – one of the most remarkable phases in the progress of mankind – was actually within the tropics. Airyana Vaedjo, the ancient cradle of the Zend, was situated to the northwest of the upper Indus, and after the great religious schism, that is to say, after the separation of the Iranians from the Brahminical institution, the language that had previously been common to them and to the Hindoos assumed among the latter people (together with the literature, habit, and condition of society) an individual form in the Magodha Madhya Desa,[7] a district that is bounded by the great chau of Himalaya and the smaller range of the Vindhya. In less ancient times the Sanscrit language and civilization advanced toward the southeast, penetrating further within the torrid zone, as my brother Wilhelm von Humboldt has shown in his greatwork on the Kavi and other languages of analogous structure.[8]

Notwithstanding the obstacles opposed

[7]See, on the Madhjadéga, properly so called, Lassens exceiler 1work, entitled Jndische Alterthumskunde, bd. i., 8. 92. The Chinese give the name of Mokiethi to the southern Bahar, situated to thesouth of the Ganges se FoeKoueKt, by ChyFaHian, 1836, p. 256).Djambudwipa is the name given to the whole of India; but the wordsalso indicate one of the four Buddhist continents.

[8]Ueber die Kawi Sprache auf der Insel Java, nebst einer Einlettunytiber die Verschiedenheit des menschlichen Sprahbaues und ihren Einfluss auf die geistige Entwickelung des Menschengeschlecht's, von Wilhelm v. Humboldt, 1836, bd. i., s. 5519.

in northern latitudes to the discovery of the laws of nature, owing to the excessivecomplication of phenomena, and the perpetual local variationsthat, in these climates, affect the movements of the atmosphereand the distribution of organic forms, it is to the inhabitantsof a small section of the temperate zone that the rest of mankind owe the earliest revelation of an intimate and rationalacquaintance with the forces governing the physical world.Moreover, it is from the same zone (which is apparently morefavorable to the progress of reason, the softening of manners,and the security of public liberty) that the germs of civilization have been carried to the regions of the tropics, as muchby the migratory movement of races as by the establishmentof colonies, differing widely in their institution from those ofthe Phenicians or Greeks.

In speaking of the influence exercised by the succession of phenomena on the greater or lesser facility of recognizing the-causes producing them, I have touched upon that importantstage of our communion with the external world, when the enjoyment arising from a knowledge of the laws, and the mutualconnection of phenomena, associates itself with the charm ofa simple contemplation of nature. That which for a longtime remains merely an object of vague intuition, by degreesacquires the certainty of positive truth ; and man, as an immortal poet has said, in our own tongueAmid ceaselesschange secks the unchanging pole.[9]

In order to trace to its primitive source

[9]This verse occurs in a poem of Schiller, entitled Der Spaziergaxg-which first appeared in 1795, in the Horgn.

the enjoyment derived from the exercise of thought, it is sufficient to cast atapid glance on the earliest dawnings of the philosophy of nature, or of the ancient doctrine of the Cosmos. We find even among the most savage nations (as my own travels enable mato attest) a certain vague, terrorstricken sense of the allpowerful unity of natural forces, and of the existence of an invisible, spiritual essence manifested in these forces, whether inunfolding the flower and maturing the fruit of the nutrienttree, in upheaving the soil of the forest, or in rending the cloudswith the might of the storm. We may here trace the revelation of a bond of union, linking together the visible world andthat higher spiritual world which escapes the grasp of thesenses. Che two become unconsciously blended together, developing in the mind of man, as a simple product of ideal conception, and independently of the aid of observation, the firstgerm of a Philosophy of Nature.

Among nations least advanced in civilization, the imagination revels in strange and fantastic creations, and, by its predilection for symbols, alike influences ideas and language. Instead of examining, men are led to conjecture, dogmatize, and interpret supposed facts that have never been observed. The inner world of thought and of feeling does not reflect the image of the external world in its primitive purity. That which in some regions of the earth manifested itself as the rudiments of natural philosophy, only to a small number of persons endowed with superior intelligence, appears in other regions, and among entire races of men, to be the result of mystic tendencies and instinctive intuitions. An intimate communion with nature, and the vivid and deep emotions thus awakened, are likewise the source from which have sprung the first impulses toward the worship and deification of the destroying and preserving forces of the universe. But by degrees, as man, after having passed through the different gradations of intellectual development, arrives at the free enjoyment of the regulating power of reflection, and learns by gradual progress, as it were,to separate the world of ideas from that of sensations, he no longer rests satisfied merely with a vague presentiment of the harmonious unity of natural forces; thought begins to fulfill its noble mission ; and observation, aided by reason, endeavors to trace phenomena to the causes from which they spring.

The history of science teaches us the difficulties that have opposed the progress of this active spirit of inquiry. Inaccurate and imperfect observations have led, by false inductions, to the great number of physical views that have been perpetuated as popular prejudices among all classes of society. Thus, by the side of a solid and scientific knowledge of natural phenomena, there has been preserved a system of the pretended results of observation, which is so much the more difficult to shake, as it denies the validity of the facts by which it may be refuted. This empiricism, the melancholy heritage transmitted to us from former times, invariably contends for the truth of its axioms with the arrogance of a narrow-minded spirit. Physical philosophy, on the other hand, when based upon science, doubts because it seeks to investigate, distinguishes between that which is certain and that which is merely probable, and strives incessantly to perfect theory by extending the circle of observation.

This assemblage of imperfect dogmas, bequeathed by one age to another, this physical philosophy, which is composed of popular prejudices, is not only injurious because it perpetuates error with the obstinacy engendered by the evidence of unobserved facts, but also because it hinders the mind from attaining to higher views of nature. Instead of seeking to discover the mean or medium point, around which oscillate, in apparent independence of forces, all the phenomena of the external world, this system delights in multiplying exceptions to the law and seeks, amid phenomena and in organic forms, for something beyond the marvel of a regular succession and an internal and progressive development. Ever inclined to believe that the order of nature is disturbed, it refuses to recognize in the present any analogy with the past and, guided by its own varying hypotheses, seeks at hazard, either in the interior of the globe or in the regions of space, for the cause of these pretended perturbations.

It is the special object of the present work to combat those errors which derive their source from a vicious empiricism and from imperfect inductions. The higher enjoyments yielded by the study of nature depend upon the correctness and the depth of our views, and upon the extent of the subjects that may be comprehended in a single glance. Increased mental cultivation has given rise, in all classes of society, to an increased desire of embellishing life by augmenting the mass of ideas, and by multiplying means for their generalization ; and this sentiment fully refutes the vague accusations advanced against the age in which we live, showing that other interests, besides the material wants of life, occupy the minds of men.

It is almost with reluctance that I am about to speak of a sentiment, which appears to arise from narrow-minded views, or from a certain weak and morbid sentimentality. I allude to the fear entertained by some persons, that nature may by degrees lose a portion of the charm and magic of her power.

As we learn more and more how to unveil her secrets, comprehend the mechanism of the movements of the heavenly bodies, and estimate numerically the intensity of natural forces. It is true that, properly speaking, the forces of nature can only exercise a magical power over us as long as their action is shrouded in mystery and darkness, and does not admit of being classed among the conditions with which experience has made us acquainted. The effect of such a power is, therefore, to excite the imagination, but that, assuredly, is not the faculty of mind we would evoke to preside over the laborious and elaborate observations by which we strive to attain to a knowledge of the greatness and excellence of the laws of the universe.

The astronomer who, by the aid of the heliometer or a double refracting prism,[10]

[10] Arago's ocular micrometer, a happy improvement upon Rochon's prismatic or double refraction micrometer. See M. Mathieu's note in Delambre's Histoire de l'Astronomie au dix-huitième Siècle, 1827.

determines the diameter of planetary bodies; who measures patiently, year after year, the meridian altitude and the relative distances of stars, or who seeks a telescopic comet in a group of nebulæ, does not feel his imagination more excited – and this is the very guarantee of the precision of his labors – than the botanist who counts the divisions of the calyx, or the number of stamens in a flower, or examines the connected or the separate teeth of the peristoma surrounding the capsule of a moss. Yet the multiplied angular measurements on the one hand, and the detail of organic relations on the other, alike aid in preparing the way for the attainment of higher views of the laws of the universe.

We must not confound the disposition of mind in the observer at the time he is pursuing his labors, with the ulterior greatness of the views resulting from investigation and the exercise of thought. The physical philosopher measures with admirable sagacity the waves of light of unequal length which by interference mutually strengthen or destroy each other, even with respect to their chemical actions; the astronomer, armed with powerful telescopes, penetrates the regions of space, contemplates, on the extremest confines of our solar system, the satellites of Uranus, or decomposes faintly sparkling points into double stars differing in color. The botanist discovers the constancy of the gyratory motion of the chara in the greater number of vegetable cells, and recognizes in the genera and natural families of plants the intimate relations of organic forms. The vault of heaven, studded with nebulæ and stars, and the rich vegetable mantle that covers the soil in the climate of palms, cannot surely fail to produce on the minds of these laborious observers of nature an impression more imposing and more worthy of the majesty of creation than on those who are unaccustomed to investigate the great mutual relations of phenomena. I cannot, therefore, agree with Burke when he says, it is our ignorance of natural things that causes all our admiration, and chiefly excites our passions.

While the illusion of the senses would make the stars stationary in the vault of heaven, Astronomy, by her aspiring labors, has assigned indefinite bounds to space; and if she has set limits to the great nebula to which our solar system belongs, it has only been to show us in those remote regions of space, which appear to expand in proportion to the increase of our optic powers, islet on islet of scattered nebulæ. The feeling of the sublime, so far as it arises from a contemplation of the distance of the stars, of their greatness and physical extent, reflects itself in the feeling of the infinite, which belongs to another sphere of ideas included in the domain of mind. The solemn and imposing impressions excited by this sentiment are owing to the combination of which we have spoken, and to the analogous character of the enjoyment and emotions awakened in us, whether we float on the surface of the great deep, stand on some lonely mountain summit enveloped in the half-transparent vapory veil of the atmosphere, or by the aid of powerful optical instruments scan the regions of space, and see the remote nebulous mass resolve itself into worlds of stars.

The mere accumulation of unconnected observations of details, devoid of generalization of ideas, may doubtlessly have tended to create and foster the deeply rooted prejudice, that the study of the exact sciences must necessarily chill the feelings, and diminish the nobler enjoyments attendant upon a contemplation of nature. Those who still cherish such erroneous views in the present age, and amid the progress of public opinion, and the advancement of all branches of knowledge, fail in duly appreciating the value of every enlargement of the sphere of intellect, and the importance of the detail of isolated facts in leading us on to general results. The fear of sacrificing the free enjoyment of nature, under the influence of scientific reasoning, is often associated with an apprehension that every mind may not be capable of grasping the truths of the philosophy of nature. It is certainly true that in the midst of the universal fluctuation of phenomena and vital forces[11] – in that inextricable network of organisms, each step that we make in the more intimate knowledge of nature leads us to the entrance of new labyrinths; but the excitement produced by a presentiment of discovery, the vague intuition of the mysteries to be unfolded, and the multiplicity of the paths before us, all tend to stimulate the exercise of thought in every stage of knowledge. The discovery of each separate law of nature leads to the establishment of some other more general law, or at least indicates to the intelligent observer its existence. Nature, as a celebrated physiologist has defined it, and

[11]Carus, Von den Urtheilen des Knochen und Schalen Geristes, 18286 Plut., in Vita Alex. Magni, cap. 7

as the word was interpreted by the Greeks and Romans, is that which is ever growing and ever unfolding itself in new forms.

The series of organic types becomes extended or perfected in proportion as hitherto unknown regions are laid open to our view by the labors and researches of travelers and observers; as living organisms are compared with those which have disappeared in the great revolutions of our planet; and as microscopes are made more perfect, and are more extensively and efficiently employed. In the midst of this immense variety, and this periodic transformation of animal and vegetable productions, we see incessantly revealed the primordial mystery of all organic development, that same great problem of metamorphosis which Göethe has treated with more than common sagacity, and to the solution of which man is urged by his desire of reducing vital forms to the smallest number of fundamental types. As men contemplate the riches of nature, and see the mass of observations incessantly increasing before them, they become impressed with the intimate conviction that the surface and the interior of the earth, the depths of the ocean, and the regions of air will still, when thousands and thousands of years have passed away, open to the scientific observer untrodden paths of discovery. The regret of Alexander cannot be applied to the progress of observation and intelligence. General considerations, whether they treat of the agglomeration of matter in the heavenly bodies, or of the geographical distribution of terrestrial organisms, are not only in themselves more attractive than special studies, but they also afford superior advantages to those who are unable to devote much time to occupations of this nature. The different branches of the study of natural history are only accessible in certain positions of social life, and do not, at every season and in every climate, present like enjoyments. Thus, in the dreary regions of the north, man is deprived for a long period of the year of the spectacle presented by the activity of the productive forces of organic nature; and if the mind be directed to one sole class of objects, the most animated narratives of voyages in distant lands will fail to interest and attract us if they do not touch upon the subjects to which we are most partial.

As the history of nations, if it were always able to trace events to their true causes, might solve the ever-recurring enigma of the oscillations experienced by the alternately progressive and retrograde movement of human society, so might also the physical description of the world, the science of the Cosmos, if it were grasped by a powerful intellect, and based upon a knowledge of all the results of discovery up to a given period, succeed in dispelling a portion of the contradictions which, at first sight, appear to arise from the complication of phenomena and the multitude of the perturbations simultaneously manifested.

The knowledge of the laws of nature, whether we can trace them in the alternate ebb and flow of the ocean, in the measured path of comets, or in the mutual attractions of multiple stars, alike increases our sense of the calm of nature, while the chimera so long cherished by the human mind in its early and intuitive contemplations, the belief in a discord of the elements, seems gradually to vanish in proportion as science extends her empire. General views lead us habitually to consider each organism as a part of the entire creation, and to recognize in the plant or the animal not merely an isolated species, but a form linked in the chain of being to other forms either living or extinct. They aid us in comprehending the relations that exist between the most recent discoveries and those which have prepared the way for them. Although fixed to one point of space, we eagerly grasp at a knowledge of that which has been observed in different and far-distant regions. We delight in tracking the course of the bold mariner through seas of polar ice, or in following him to the summit of that volcano of the Antarctic pole, whose fires may be seen from afar, even at midday. It is by an acquaintance with the results of distant voyages that we may learn to comprehend some of the marvels of terrestrial magnetism, and be thus led to appreciate the importance of the establishments of the numerous observatories which in the present day cover both hemispheres, and are designed to note the simultaneous occurrence of perturbations, and the frequency and duration of magnetic storms.

Let me be permitted here to touch upon a few points connected with discoveries, whose importance can only be estimated by those who have devoted themselves to the study of the physical sciences generally. Examples chosen from among the phenomena to which special attention has been directed in recent times will throw additional light upon the preceding considerations. Without a preliminary knowledge of the orbits of comets, we would be unable to duly appreciate the importance attached to the discovery of one of these bodies, whose elliptical orbit is included in the narrow limits of our solar system and which has revealed the existence of an ethereal fluid, tending to diminish its centrifugal force and the period of its revolution.

The superficial half-knowledge, so characteristic of the present day, which leads to the introduction of vaguely comprehended scientific views into general conversation, also gives rise, under various forms, to the expression of alarm at the supposed danger of a collision between celestial bodies or disturbance in the climatic relations of our globe. These phantoms of the imagination are so much the more injurious as they derive their source from dogmatic pretensions to true science. The history of the atmosphere and the annual variations of its temperature extend already sufficiently far back to show the recurrence of slight disturbances in the mean temperature of any given place and thus afford sufficient guarantee against the exaggerated apprehension of a general and progressive deterioration of the climates of Europe. Jinckes comet, which is one of the three interior comets, completes its course in 1200 days, but from the form and position of its orbit, it is as little dangerous to the earth as Halley's great comet, whose revolution is not completed in less than seventy-six years (and which appeared less brilliant in 1835 than it had done in 1759). The interior comet of Biela intersects the earth's orbit, it is true, but it can only approach our globe when its proximity to the sun coincides with our winter solstice.

The quantity of heat received by a planet, and whose unequal distribution determines the meteorological variations of its atmosphere, depends alike upon the light-engendering force of the sun; that is to say, upon the condition of its gaseous coverings, and upon the relative position of the planet and the central body.

There are variations, it is true, which, in obedience to the laws of universal gravitation, affect the form of the earth's orbit and the inclination of the ecliptic, that is, the angle which the axis of the earth makes with the plane of its orbit; but these periodical variations are so slow, and are restricted within such narrow limits, that their thermic effects would hardly be appreciable by our instruments in many thousands of years. The astronomical causes of a refrigeration of our globe, and of the diminution of moisture at its surface, and the nature and frequency of certain epidemics phenomena which are often discussed in the present day according to the benighted views of the Middle Ages ought to be considered as beyond the range of our experience in physics and chemistry.

Physical astronomy presents us with other phenomena, which cannot be fully comprehended in all their vastness without a previous acquirement of general views regarding the forces that govern the universe. Such, for instance, are the innumerable double stars, or rather suns, which revolve round one common center of gravity, and thus reveal in distant worlds the existence of the

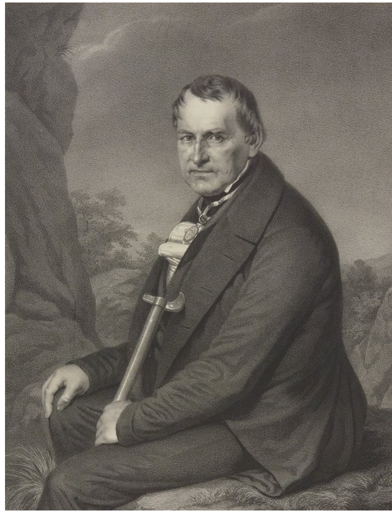

Figure 1.2: Christian Leopold von Buch (1774 – 1853) was a German geologist and paleontologist. (From Wikipedia). Image: Lithograph by C. Fischer based on a painting by Carl Joseph Begas, 1850. Public domain.

Newtonian law; the larger or smaller number of spots upon the sun, that is to say, the openings formed through the luminous and opaque atmosphere surrounding the solid nucleus; and the regular appearance, about the 13th of November and the 11th of August, of shooting stars, which probably form part of a belt of asteroids, intersecting the earth's orbit, and moving with planetary velocity.

Descending from the celestial regions to the earth, we would fain inquire into the relations that exist between the oscillations of the pendulum in air (the theory of which has been perfected by Bessel) and the density of our planet; and how the pendulum, acting the part of a plummet, can, to a certain extent, throw light upon the geological constitution of strata at great depths. By means of this instrument, we are enabled to trace the striking analogy which exists between the formation of the granular rocks composing the lava currents ejected from active volcanoes, and those endogenous masses of granite, porphyry, and serpentine, which, issuing from the interior of the earth, have broken, as eruptive rocks, through the secondary strata, and modified them by contact, either in rendering them harder by the introduction of silex, or reducing them into dolomite, or, finally, by inducing within them the formation of crystals of the most varied composition. The elevation of sporadic islands, of domes of trachyte, and cones of basalt, by the elastic forces emanating from the fluid interior of our globe, has led one of the first geologists of the age, Leopold von Buch, to the theory of the elevation of continents, and of mountain chains generally. This action of subterranean forces in breaking through and elevating strata of sedimentary rocks, of which the coast of Chile, in consequence of a great earthquake, furnished a recent example, leads to the assumption that the pelagic shells found by M. Bonpland and myself on the ridge of the Andes, at an elevation of more than 15,000 English feet, may have been conveyed to so extraordinary a position, not by a rising of the ocean, but by the agency of volcanic forces capable of elevating into ridges the softened crust of the earth.

I apply the term volcanic, in the widest sense of the word, to every action exercised by the interior of a planet on its external crust. The surface of our globe, and that of the moon, manifest traces of this action, which in the former, at least, has varied during the course of ages. Those who are ignorant of the fact that the internal heat of the earth increases so rapidly with the increase of depth that granite is in a state of fusion about twenty or thirty geographical miles below the surface,[12] cannot have a clear conception of the causes, and the simultaneous occurrence of volcanic eruptions at places widely removed from one another, or of the extent and intersection of circles of commotion in earthquakes, or of the uniformity of temperature, and equality of chemical composition observed in thermal springs during a long course of years. The quantity of heat peculiar to a

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[12]The determinations usually given of the point of fusion are in general much too high for refracting substances. According to the very accurate researches of Mitscherlich, the melting point of granite can hardly exceed 2372°F.

[Dr. Mantell states in The Wonders of Geology, 1848, vol. i., p. 34, that this increase of temperature amounts to 1°F for every fifty-four feet of vertical depth.] – Tr.

planet is, however, a matter of such importance being the result of its primitive condensation, and varying according to the nature and duration of the radiation that the study of this subject may throw some degree of light on the history of the atmosphere, and the distribution of the organic bodies embedded in the solid crust of the earth. This study enables us to understand how a tropical temperature, independent of latitude (that is, of the distance from the poles), may have been produced by deep fissures remaining open, and exhaling heat from the interior of the globe, at a period when the earth's crust was still furrowed and rent, and only in a state of semi-solidification; and a primordial condition is thus revealed to us, in which the temperature of the atmosphere, and climates generally, were owing rather to a liberation of caloric and of different gaseous emanations (that is to say, rather to the energetic reaction of the interior on the exterior) than to the position of the earth with respect to the central body, the sun.

The cold regions of the earth contain, deposited in sedimentary strata, the products of tropical climates; thus, in the coal formations, we find the trunks of palms standing upright amid conifer, tree ferns, goniatites, and fishes having rhomboidal osseous scales;[13] in the Jura limestone, colossal skeletons of crocodiles, ple-

[13]See the classical work on the fishes of the Old World by Agassiz, Rech. sur les Poissons Fossiles, 1834, vol. i., p. 38; vol. ii., p. 3, 28, 34, App., p. 6. The whole genus of Amblypterus, Ag., nearly allied to Palaeoniscus (called also Paleothrissum), lies buried beneath the Jura formations in the old carboniferous strata. Scales which, in some fishes, as in the family of Lepidoides (order of Ganoides), are formed like teeth and covered in certain parts with enamel, belong, after the Placoides, to the oldest forms of fossil fishes; their living representatives are still found in two genera, the Bichir of the Nile and Senegal, and the Lepidosteus of the Ohio.

siosaurs, planulites, and stems of the cycads; in the chalk formations, small polythalamia and bryozoa, whose species still exist in our seas; in tripoli, or polishing slate, in the semiopal and the farinaceous opal or mountain meal, agglomerations of siliceous infusoria, which have been brought to light by the powerful microscope of Ehrenberg;[14] and, lastly, in transported soils, and in certain caves, the bones of elephants, hyenas, and lions. An intimate acquaintance with the physical phenomena of the universe leads us to regard the products of warm latitudes that are thus found in a fossil condition in

[14][The polishing slate of Bilin is stated by M. Ehrenberg to formaseries of strata fourteen feet in thickness, entirely made up of the siliccous shells of Gaillonelle, of such extreme minuteness that a cubicinch of the stone contains fortyone thousand millions The Bergmeht(mountain meal or fossil farina) of San Fiora, in Tuscany, is one masaof animalculites. See the interesting work of G. A, Mantell, On teeMedals of Creation, vol. i., p. 223.] – Tr.

northern regions not merely as incentives to barren curiosity, but as subjects awakening deep reflection and opening new sources of study.

The number and the variety of the objects I have alluded to give rise to the question of whether general considerations of physical phenomena can be made sufficiently clear to persons who have not acquired a detailed and special knowledge of descriptive natural history, geology, or mathematical astronomy. I think we ought to distinguish here between him whose task it is to collect the individual details of various observations and study the mutual relations existing among them, and him to whom these relations are to be revealed under the form of general results. The former should be acquainted with the specialties of phenomena, that he may arrive at a generalization of ideas as the result, at least in part, of his own observations, experiments, and calculations. It cannot be denied that where there is an absence of positive knowledge of physical phenomena, the general results which impart so great a charm to the study of nature cannot all be made equally clear and intelligible to the reader. But still, I venture to hope that in the work which I am now preparing on the physical laws of the universe, the greater part of the facts advanced can be made manifest without the necessity of appealing to fundamental views and principles. The picture of nature thus drawn, notwithstanding the want of distinctness of some of its outlines, will not be the less able to enrich the intellect, enlarge the sphere of ideas, and nourish and vivify the imagination.

There is, perhaps, some truth in the accusation advanced against many German scientific works, that they lessen the value of general views by an accumulation of detail, and do not sufficiently distinguish between those great results which form, as it were, the beacon lights of science, and the long series of means by which they have been attained. This method of treating scientific subjects led the most illustrious of our poets[15] to exclaim, with impatience, "The Germans have the art of making science inaccessible." An edifice cannot produce a striking effect until the scaffolding is removed, that had of necessity been used during its erection. Thus the uniformity of figure observed in the distribution of continental masses, which all terminate

[15]Göethe, in Die Aphorismen uber Naturwissenschaft, bd. l.. 8. 155 (Werke kleine Ausgabe, von 1833.)

toward the south in a pyramidal form, and expand toward the north (a law that determines the nature of climates, the direction of currents in the ocean and the atmosphere, and the transition of certain types of tropical vegetation toward the southern temperate zone), may be clearly apprehended without any knowledge of the geodesical and astronomical operations by means of which these pyramidal forms of continents have been determined. In like manner, physical geography teaches us by how many leagues the equatorial axis exceeds the polar axis of the globe, and shows us the mean equality of the flattening of the two hemispheres, without entailing on us the necessity of giving the detail of the measurement of the degrees in the meridian, or the observations on the pendulum, which have led us to know that the true figure of our globe is not exactly that of a regular ellipsoid of revolution, and that this irregularity is reflected in the corresponding irregularity of the movements of the moon.

The views of comparative geography have been specially enlarged by that admirable work, Erdkunde im Verhältniss zur Natur und zur Geschichte, in which Carl Ritter so ably delineates the physiognomy of our globe, and shows the influence of its external configuration on the physical phenomena on its surface, on the migrations, laws, and manners of nations, and on all the principal historical events enacted upon the face of the earth.

France possesses an immortal work, L'Exposition du Système du Monde, in which the author has combined the results of the highest astronomical and mathematical labors, and presented them to his readers free from all processes of demonstration. The structure of the heavens is here reduced to the simple solution of a great problem in mechanics; yet Laplace's work has never yet been accused of incompleteness and want of profundity.

The distinction between dissimilar subjects, and the separation of the general from the special, are not only conduciveto the attainment of perspicuity in the composition of a physial history of the universe, but are also the means by whicha character of greater elevation may be imparted to the studyof nature. By the suppression of all unnecessary detail, thegreat masses are better seen, and the reasoning faculty is enabled to grasp all that might otherwise escape the limited rangeof the senses.

The exposition of general results has, it must be owned, been singularly facilitated by the happy revolution experienced since the close of the last century, in the condition of all the special sciences, more particularly of geology, chemistry, and descriptive natural history. In proportion as laws admit of more general application, and as sciences mutually enrich each other, and by their extension become connected together in more numerous and more intimate relations, the development of general truths may be given with conciseness devoid of superficiality. On being first examined, all phenomena appear to be imagined, and it is only by the result of a multiplicity of observations, combined by reason, that we are able to trace the mutual relations existing between them. If, however, in the present age, which is so strongly characterized by a brilliant course of scientific discoveries, we perceive a want of connection in the phenomena of certain sciences, we may anticipate the revelation of new facts, whose importance will probably be commensurate with the attention directed to these branches of study. Expectations of this nature may be entertained with regard to meteorology, several parts of optics, and to radiating heat, and electromagnetism, since the admirable discoveries of Melloni and Faraday. A fertile field is here opened to discovery, although the voltaic pile has already taught us the intimate connection existing between electric, magnetic, and chemical phenomena. Who will venture to affirm that we have any precise knowledge, in the present day, of that part of the atmosphere which is not oxygen, or that thousands of gaseous substances affecting our organs may not be mixed with the nitrogen, or, finally, that we have even discovered the whole number of the forces which pervade the universe?

It is not the purpose of this essay on the physical history of the world to reduce all sensible phenomena to a small number of abstract principles, based on reason only. The physical history of the universe, whose exposition I attempt to develop, does not pretend to rise to the perilous abstractions of a purely rational science of nature, and is simply a physical geography, combined with a description of the regions of space and the bodies occupying them. Devoid of the profoundness of a purely speculative philosophy, my essay on the Cosmos treats of the contemplation of the universe, and is based upon a rationalempiricism, that is to say, upon the results of the facts registered by science, and tested by the operations of the intellect. It is within these limits alone that the work, which I now venture to undertake, appertains to the sphere of labor to which I have devoted myself throughout the course of my long scientific career. The path of inquiry is not unknown to me, although it may be pursued by others with greater success. The unity which I seek to attain in the development of the great phenomena of the universe is analogous to that which historical composition is capable of acquiring. All points relating to the accidental individualities, and the essential variations of the actual, whether in the form and arrangement of natural objects in the struggle of man against the elements, or of nations against nations, do not admit of being based only on a rational foundation, that is to say, of being deduced from ideas alone.

It seems to me that a like degree of empiricism attaches to the Description of the Universe and to Civil History; but in reflecting upon physical phenomena and events, and tracing their causes by the process of reason, we become more and more convinced of the truth of the ancient doctrine, that the forces inherent in matter, and those which govern the moral world, exercise their action under the control of primordial necessity, and in accordance with movements occurring periodically after longer or shorter intervals.

It is this necessity, this occult but permanent connection, this periodical recurrence in the progressive development of forms, phenomena, and events, which constitute nature, obedient to the first impulse imparted to it. Physics, as the term signifies, is limited to the explanation of the phenomena of the material world by the properties of matter. The ultimate object of the experimental sciences is, therefore, to discover laws, and to trace their progressive generalization. All that exceeds this goes beyond the province of the physical description of the universe and appertains to a range of higher speculative views.

Emanuel Kant, one of the few philosophers who have escaped the imputation of impiety, has defined with rare sagacity the limits of physical explanations, in his celebrated essay "On the Theory and Structure of the Heavens", published at Königsberg in 1755.

The study of a science that promises to lead us through the vast range of creation may be compared to a journey in a far distant land. Before we set forth, we consider, and often with distrust, our own strength, and that of the guide we have chosen. But the apprehensions which have originated in the abundance and the difficulties attached to the subjects we would embrace recede from view as we remember that with the increase of observations in the present day there has also arisen a more intimate knowledge of the connection existing among all phenomena. It has not unfrequently happened that the researches made at remote distances have often and unexpectedly thrown light upon subjects which had long resisted the attempts made to explain them within the narrow limits of our own sphere of observation. Organic forms that had long remained isolated, both in the animal and vegetable kingdom, have been connected by the discovery of intermediate links or stages of transition. The geography of beings endowed with life attains completeness as we see the species, genera, and entire families belonging to one hemisphere, reflected, as it were, in analogous animal and vegetable forms in the opposite hemisphere. These are, so to speak, the equivalents which mutually personate and replace one another in the great series of organisms. These connecting links and stages of transition may be traced, alternately, in a deficiency or an excess of development of certain parts, in the mode of junction of distinct organs, in the differences in the balance of forces, or in a resemblance to intermediate forms, which are not permanent, but merely characteristic of certain phases of normal development. Passing from the consideration of beings endowed with life to that of inorganic bodies, we find many striking illustrations of the high state of advancement to which modern geology has attained. We thus see, according to the grand views of Elie de Beaumont, how chains of mountains dividing different climates and floras and different races of men reveal to us their relative age, both by the character of the sedimentary strata they have uplifted, and by the directions which they follow over the long fissures with which the earth's crust is furrowed. Relations of superposition of trachyte and of syenitic porphyry, of diorite and of serpentine, which remain doubtful when considered in the auriferous soil of Hungary in the rich platinum districts of the Ural, and on the southwestern declivity of the Siberian Altai, are elucidated by the observations that have been made on the plateaus of Mexico and Antioquia, and in the unhealthy ravines of Choco. The most important facts on which the physical history of the world has been based in modern times have not been accumulated by chance. It has at length been fully acknowledged, and the conviction is characteristic of the age, that the narratives of distant travels, too long occupied in the mere recital of hazardous adventures, can only be made a source of instruction where the traveler is acquainted with the condition of the science he would enlarge and is guided by reason in his researches.

It is by this tendency to generalization, which is only dangerous in its abuse, that a great portion of the physical knowledge already acquired may be made the common property of all classes of society; but, in order to render the instruction imparted by these means commensurate with the importance of the subject, it is desirable to deviate as widely as possible from the imperfect compilations designated, till the close of the eighteenth century, by the inappropriate term of popular knowledge. I take pleasure in persuading myself that scientific subjects may be treated of in language at once dignified, grave, and animated, and that those who are restricted within the circumscribed limits of ordinary life, and have long remained strangers to an intimate communion with nature, may thus have opened to them one of the richest sources of enjoyment, by which the mind is invigorated by the acquisition of new ideas. Communion with nature awakens within us perceptive faculties that had long lain dormant; and we thus comprehend at a single glance the influence exercised by physical discoveries on the enlargement of the sphere of intellect, and perceive how a judicious application of mechanics, chemistry, and other sciences may be made conducive to national prosperity.

A more accurate knowledge of the connection of physical phenomena will also tend to remove the prevalent error that all branches of natural science are not equally important in relation to general cultivation and industrial progress. An arbitrary distinction is frequently made between the various degrees of importance appertaining to mathematical sciences, to the study of organized beings, the knowledge of electromagnetism, and investigations of the general properties of matter in its different conditions of molecular aggregation; and it is not uncommon presumptuously to affix a supposed stigma upon researches of this nature, by terming them purely theoretical, forgetting, although the fact has been long attested, that in the observation of a phenomenon, which at first sight appears to be wholly isolated, may be concealed the germ of a great discovery. When Aloysio Galvani first stimulated the nervous fiber by the accidental contact of two heterogeneous metals, his contemporaries could never have anticipated that the action of the voltaic pile would discover to us, in the alkalies, metals of a silvery luster, so light as to swim on water, and eminently inflammable; or that it would become a powerful instrument of chemical analysis, and at the same time a thermoscope and a magnet. When Huygens first observed, in 1678, the phenomenon of the polarization of light, exhibited in the difference between the two rays into which a pencil of light divides itself in passing through a doubly refracting crystal, it could not have been foreseen that, a century and a half later, the great philosopher Arago would, by his discovery of chromatic polarization, be led to discern, by means of a small fragment of Iceland spar, whether solar light emanates from a solid body or a gaseous covering, or whether comets transmit light directly or merely by reflection.[16]

An equal appreciation of all branches of the mathematical, physical, and natural sciences is a special requirement of the present age, in which the material wealth and the growing prosperity of nations are principally based upon a more enlightened employment of the products

[16] Aragos Discoveries in the year 1811.Delambres Histoire de Ast., p. 652. (Passage already quoted.)

and forces of nature. The most superficial glance at the present condition of Europe reveals that a diminution, or even a total annihilation of national prosperity, must be the award of those states who shrink with slothful indifference from the great struggle of rival nations in the career of the industrial arts. It is with nations as with nature, which, according to a happy expression of Göethe[17], "knows no pause in progress and development, and attaches her curse on all inaction". The propagation of an earnest and sound knowledge of science can therefore alone avert the dangers of which I have spoken. Man cannot act upon nature, or appropriate her forces to his own use, without comprehending their full extent, and having an intimate

[17] Göethe, in Die Aphorismen über Naturwissenschaft. Werke, bd. 1.,a4

acquaintance with the laws of the physical world. Bacon has said that, in human societies, knowledge is power. Both must rise and sink together. But the knowledge that results from the free action of thought is at once the delight and the indestructible prerogative of man; and in forming part of the wealth of mankind, it not unfrequently serves as a substitute for the natural riches, which are but sparingly scattered over the earth. Those states which take no active part in the general industrial movement, in the choice and preparation of natural substances, or in the application of mechanics and chemistry, and among whom this activity is not appreciated by all classes of society, will infallibly see their prosperity diminish in proportion as neighboring countries become strengthened and invigorated under the genial influence of arts and sciences.

As in nobler spheres of thought and sentiment, in philosophy, poetry, and the fine arts, the object at which we aim ought to be an inward one - an ennoblement of the intellect. So ought we likewise, in our pursuit of science, to strive after a knowledge of the laws and the principles of unity that pervade the vital forces of the universe; and it is by such a course that physical studies may be made subservient to the progress of industry, which is a conquest of mind over matter. By a happy connection of causes and effects, we often see the useful linked to the beautiful and the exalted. The improvement of agriculture in the hands of freemen, and on properties of a moderate extent, the flourishing state of the mechanical arts freed from the trammels of municipal restrictions, the increased impetus imparted to commerce by the multiplied means of contact of nations with each other, are all brilliant results of the intellectual progress of mankind, and of the amelioration of political institutions, in which this progress is reflected. The picture presented by modern history ought to convince those who are tardy in awakening to the truth of the lesson it teaches.

Nor let it be feared that the marked predilection for thestudy of nature, and for industrial progress, which is so characteristic of the present age, should necessarily have a tendency to retard the noble exertions of the intellect in the domainsof philosophy, classical history, and antiquity, or to deprivethe arts by which life is embellished of the vivifying breath of.magination. Where all the germs of civilization are developed beneath the wgis of free institutions and wise legislation,there is no cause for apprehending that any one branch ofsnowledge should be cultivated to the prejudice of others.All afford the state precious fruits, whether they yield nourishment to man and constitute his physical wealth, or whether,more permanent in their nature, they transmit in the works .of mind the glory of nations to remotest posterity. The Spartans, notwithstanding their Doric austerity, prayed the godsto grant them "the beautiful with the good."[18]

I will no longer dwell upon the considerations of the influence exercised by the mathematical and physical sciences on all that appertains to the material wants of social life, for the vast extent of the course

[18]Pseudo-Plato.Alcib., xi., p. 184, ed. Steph.; Plut., Instituta Laconica, p. 253, ed. Hutten.

on which I am entering forbids me to insist further upon the utility of these applications. Accustomed to distant excursions, I may, perhaps, have erred in describing the path before us as more smooth and pleasant than it really is, for such is wont to be the practice of those who delight in guiding others to the summits of lofty mountains; they praise the view even when a great part of the distant plains lie hidden by clouds, knowing that this half-transparent vapory veil imparts to the scene a certain charm from the power exercised by the imagination over the domain of the senses. In like manner, from the height occupied by the physical history of the world, all parts of the horizon will not appear equally clear and well defined. This indistinctness will not, however, be wholly owing to the present imperfect state of some of the sciences, but in part, likewise, to the unskillfulness of the guide who has imprudently ventured to ascend these lofty summits.

The object of this introductory notice is not, however, solely to draw attention to the importance and greatness of the physical history of the universe, for in the present day these are too well understood to be contested, but likewise to prove how, without detriment to the stability of special studies, we may be enabled to generalize our ideas by concentrating them in one common focus, and thus arrive at a point of view from which all the organisms and forces of nature may be seen as one living, active whole, animated by one sole impulse. "Nature, as Schelling remarks in his poetic discourse on art, is not an inert mass; and to him who can comprehend her vast sublimity, she reveals herself as the creative force of the universe before all time, eternal, ever active, she calls to life all things, whether perishable or imperishable."

By uniting, under one point of view, both the phenomena of our own globe and those presented in the regions of space, we embrace the limits of the science of the Cosmos, and convert the physical history of the globe into the physical history of the universe, the one term being modeled upon that of the other. This science of the Cosmos is not, however, to be regarded as a mere encyclopedic aggregation of the most important and general results that have been collected together from special branches of knowledge. These results are nothing more than the materials for a vast edifice, and their combination can not constitute the physical history of the world, whose exalted part it is to show the simultaneous action and the connecting links of the forces which pervade the universe. The distribution of organic types in different climates and at different elevations - that is to say, the geography of plants and animals - differs as widely from botany and descriptive zoology as geology does from mineralogy, properly so called. The physical history of the universe must not, therefore, be confounded with the encyclopedias of the Natural Sciences, as they have hitherto been compiled, and whose title is as vague as their limits are ill defined. In the work before us, partial facts will be considered only in relation to the whole.

The higher the point of view, the greater is the necessity for a systematic mode of treating the subject in language at once animated and picturesque.

But thought and language have ever been most intimately allied. If language, by its originality of structure and its native richness, can, in its delineations, interpret thought with grace and clearness, and if, by its happy flexibility, it can paint with vivid truthfulness the objects of the external world; it reacts at the same time upon thought, and animates it, as it were, with the breath of life. It is this mutual reaction which makes words more than mere signs and forms of thought; and the beneficent influence of a language is most strikingly manifested on its native soil, where it has sprung spontaneously from the minds of the people, whose character it embodies. Proud of a country that seeks to concentrate her strength in intellectual unity, the writer recalls with delight the advantages he has enjoyed in being permitted to express his thoughts in his native language; and truly happy is he who, in attempting to give a lucid exposition of the great phenomena of the universe, is able to draw from the depths of a language, which, through the free exercise of thought, and by the effusions of creative fancy, has for centuries past exercised so powerful an influence over the destinies of man.

1.2 Limits and Method of Exposition of the Physical Description of the Universe.

I have endeavored, in the preceding part of my work, to explain and illustrate, by various examples, how the enjoyments presented by the aspect of nature, varying as they do in the sources from whence they flow, may be multiplied and ennobled by an acquaintance with the connection of phenomena and the laws by which they are regulated. It remains, then, for me to examine the spirit of the method in which the exposition of the physical description of the universe should be conducted, and to indicate the limits of this science in accordance with the views I have acquired in the course of my studies and travels in various parts of the earth. I trust I may flatter myself with a hope that a treatise of this nature will justify the title I have ventured to adopt for my work, and exonerate me from the reproach of a presumption that would be doubly reprehensible in a scientific discussion.

Before entering upon the delineation of the partial phenomena which are found to be distributed in various groups, I would consider a few general questions intimately connected together, and bearing upon the nature of our knowledge of the external world and its different relations, in all epochs of history and in all phases of intellectual advancement. Under this head will be comprised the following considerations:

1. The precise limits of the physical description of the universe, considered as a distinct science.

2. A brief enumeration of the totality of natural phenomena, presented under the form of a general delineation of nature.

3. The influence of the external world on the imagination and feelings, which has acted in modern times as a power-

ful impulse toward the study of natural science, by giving animation to the description of distant regions and to the delineation of natural scenery, as far as it is characterized by vegetable physiognomy and by the cultivation of exotic plants, and their arrangement in well-contrasted groups.

4. The history of the contemplation of nature, or the progressive development of the idea of the Cosmos, considered with reference to the historical and geographical facts that have led to the discovery of the connection of phenomena.

The higher the point of view from which natural phenomena may be considered, the more necessary it is to circumscribe the science within its just limits, and to distinguish it from all other analogous or auxiliary studies.

Physical cosmography is founded on the contemplation of all created things - all that exists in space, whether as substances or forces - that is, all the material beings that constitute the universe. The science which I would attempt to define presents itself, therefore, to man, as the inhabitant of the earth, under a twofold form: as the earth itself and the regions of space. It is with a view of showing the actual character and the independence of the study of physical cosmography, and at the same time indicating the nature of its relations to general physics, descriptive natural history, geology, and comparative geography, that I will pause for a few moments to consider that portion of the science of the Cosmos which concerns the earth. As the history of philosophy does not consist of a mere material enumeration of the philosophical views entertained in different ages, neither should the physical description of the universe be a simple encyclopedic compilation of the sciences we have enumerated. The difficulty of defining the limits of intimately connected studies has been increased, because for centuries it has been customary to designate various branches of empirical knowledge by terms which admit either too wide or too limited a definition of the ideas which they were intended to convey, and are, besides, objectionable from having had a different signification in those classical languages of antiquity from which they have been borrowed. The terms physiology, physics, natural history, geology, and geography arose, and were commonly used, long before clear ideas were entertained of the diversity of objects embraced by these sciences, and consequently of their reciprocal limitation. Such is the influence of long habit upon language, that by one of the nations of Europe most advanced in civilization the word "physic" is applied to medicine, while in a society of justly deserved universal reputation, technical chemistry, geology, and astronomy (purely experimental sciences) are comprised under the head of "Philosophical Transactions."

An attempt has often been made, and almost always in vain,to substitute new and more appropriate terms for these ancientdesignations, which, notwithstanding their undoubted vaguehess, are now generally understood. These changes have beenproposed, for the most part, by those who have occupied themselves with the general classification of the various branchesof knowledge, from the first appearance of the great encyclopedia (Margarita Philosophica) of Gregory Reisch,[19]

[19]The Margarita Philosophica of Gregory Reisch, prior of the Chartreuse at Freiburg, first appeared under the following title Zpitomeomnis Philosophie, alias Margarita Philosophica, tractans de omni generiscibili. The Heidelberg edition (1486), and that of Strasburg (1504),both bear this title, but the first part was suppressed in the Freiburgedition of the same year, as well as in the twelve subsequent editions,which succeeded one another, at short intervals, till 1535. This workexercised a great influence on the diffusion of mathematical and physical sciences toward the beginning of the sixteenth century, and Unasles,the learned author of L'Apergu Historique des Méthodes en Géoméire(1837), has shown the great importance of Reischs Encyclopedia inthe history of mathematics in the Middle Ages. I have had recourseto a passage in the Margarita Philosophica, found only in the editionof 1513, to elucidate the important question of the relations betweenthe statements of the geographer of SaintDie, Hylacomilus (MartinWaldseemiiller), the first who gave the name of America to the NewContinent, and those of Amerigo Vespucci, René, King of Jerusalemand Duke of Lorraine, as also those contained in the celebrated editionsof Ptolemy of 1513 and 1522. See my Examen Critique de la Géographie du Nouveau Continent, et des Progrés de l Astronomie Nautiqueauz 15e et 16e

prior ofthe Chartreuse at Freiburg, toward the close of the fifteenthcentury, to Lord Bacon, and from Bacon to DAlembert ; andin recent times to an eminent physicist, André Marie Ampére.[20]

The selection of an inappropriate Greek nomenclature has perhaps been even more prejudicial to the last of these attemptsthan the injudicious use of binary divisions and the excessivetnultiplication.of groups.

The physical description of the world, considering the universe as an object of the external senses, does undoubtedly require the aid of general physics and of descriptive natural history, but the contemplation of all created things, which are linked to-

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Siécles, t. iv., p. 99125.

[20] Ampére, Essai sur la Phil. des Sciences, 1834, p. 25. Whewell, Philosophy of the Inductive Sciences, vol, ii., p. 277. Park, Pantology p. 87

gether, and form one whole, animated by internal forces, gives to the science we are considering a peculiar character. Physical science considers only the general properties of bodies; it is the product of abstraction, a generalization of perceptible phenomena; and even in the work in which were laid the first foundations of general physics, in the eight books on physics of Aristotle,[21] all the phenomena of nature are considered as depending upon the primitive and vital action of one sole force, from which emanate all the movements of the universe. The terrestrial portion of physical cosmography, for which I would willingly retain the expressive designation of physical geography, treats of the

[21] All changes in the physical world may be reduced to motion. Aristot., Phys. Ausc., iii., 1 and 4, p. 200, 201. Bekker, viii., 1, 8, and D, p. 250, 262, 265. De Genere et Corr., ii., 10, p. 336. PseudoAristot., De Mundo. ynp. vi., p. 398.

distribution of magnetism in our planet with relation to its intensity and direction, but does not enter into a consideration of the laws of attraction or repulsion of the poles, or the means of eliciting either permanent or transitory electromagnetic currents. Physical geography depicts in broad outlines the even or irregular configuration of continents, the relations of superficial area, and the distribution of continental masses in the two hemispheres, a distribution which exercises a powerful influence on the diversity of climate and the meteorological modifications of the atmosphere; this science defines the character of mountain chains, which, having been elevated at different epochs, constitute distinct systems, whether they run in parallel lines or intersect one another; determines the mean height of continents above the level of the sea, the position of the center of gravity of their volume, and the relation of the highest summits of mountain chains to the mean elevation of their crests, or to their proximity with the seashore. It depicts the eruptive rocks as principles of movement, acting upon the sedimentary rocks by traversing, uplifting, and inclining them at various angles; it considers volcanoes either as isolated, or ranged in single or indouble series, and extending their sphere of action to various distances, either by raising long and narrow lines of rocks, or by means of circles of commotion, which expand or diminish in diameter in the course of ages. This terrestrial portion of the science of the Cosmos describes the strife of the liquid element with the solid land; it indicates the features possessed in common by all great rivers in the upper and lower portion of their course, and in their mode of bifurcation when their basins are unclosed; and shows us rivers breaking through the highest mountain chains, or following for a long time course parallel to them, either at their base, or at a considerable distance, where the elevation of the strata of the mountain system and the direction of their inclination correspond to the configuration of the tableland. It is only the general results of comparative orography and hydrography that belong to the science whose true limits I am desirous of determining and not the special enumeration of the greatest elevations of our globe, of active volcanoes, of rivers, and the number of their tributaries, these details falling rather within the domain of geography, properly so called. We would here only consider phenomena in their mutual connection, and in their relations to different zones of our planet, and to its physical constitution generally. The specialties both of inorganic and organized matter, classed according to analogy of form and composition, undoubtedly constitute a most interesting branch of study, but they appertain to a sphere of ideas having no affinity with the subject of this work.

The description of different countries certainly furnishes us with the most important materials for the composition of a physical geography; but the combination of these different descriptions, ranged in series, would as little give us a true image of the general conformation of the irregular surface of our globe, as a succession of all the floras of different regions would constitute that which I designate as a Geography of Plants. It is by subjecting isolated observations to the process of thought, and by combining and comparing them, that we are enabled to discover the relations existing in common between the climatic distribution of beings and the individuality of organic forms (in the morphology or descriptive natural history of plants and animals); and it is by induction that we are led to comprehend numerical laws, the proportion of natural families to the whole number of species, and to designate the latitude or geographical position of the zones in whose plains each organic form attains the maximum of its development. Considerations of this nature, by their tendency to generalization, impress a nobler character on the physical description of the globe, and enable us to understand how the aspect of the scenery, that is to say, the impression produced upon the mind by the physiognomy of the vegetation, depends upon the local distribution, the number, and the luxuriance of growth of the vegetable forms predominating in the general mass. The catalogues of organized beings, to which was formerly given the pompous title of Systems of Nature, present us with an admirably connected arrangement by analogies of structure, either in the perfected development of these beings, or in the different phases which, in accordance with the views of a spiral evolution, affect in vegetables the leaves, bracts, calyx, corolla, and fructifying organs; and in animals, with more or less symmetrical regularity, the cellular and fibrous tissues, and their perfect or but obscurely developed articulations. But these pretended systems of nature, however ingenious their mode of classification may be, do not show us organic beings as they are distributed in groups throughout our planet, according to their different relations of latitude and elevation above the level of the sea, and to climatic influences, which are owing to general and often very remote causes. The ultimate aim of physical geography is, however, as we have already said, to recognize unity in the vast diversity of phenomena, and by the exercise of thought and the combination of observations, to discern the constancy of phenomena in the midst of apparent changes. In the exposition of the terrestrial portion of the Cosmos, it will occasionally be necessary to descend to very special facts; but this will only be in order to recall the connection existing between the actual distribution of organic beings over the globe, and the laws of the ideal classification by natural families, analogy of internal organization, and progressive evolution.

It follows from these discussions on the limits of the various sciences, and more particularly from the distinction which must necessarily be made between descriptive botany (morphology of vegetables) and the geography of plants, that in the physical history of the globe, the innumerable multitude of organized bodies which embellish creation are considered rather according to zones of habitation or stations, and to differently inflected isothermal bands, than with reference to the principles of gradation in the development of internal organism. Notwithstanding this, botany and zoology, which constitute the natural history of all organized beings, are the fruitful sources whence we draw the materials necessary to give a solid basis to the study of the mutual relations and connection of phenomena.

We will here subjoin one important observation by way of elucidating the connection of which we have spoken. The first general glance over the vegetation of a vast extent of a continent shows us forms the most dissimilar - Graminee and Orchidex, Conifere and oaks, in local approximation to one another; while natural families and genera, instead of being locally associated, are dispersed as if by chance. This dispersion is, however, only apparent. The physical description of the globe teaches us that vegetation everywhere presents numerically constant relations in the development of its forms and types; that in the same climates, the species which are wanting in one country are replaced in a neighboring one by other species of the same family; and that this law of substitution, which seems to depend upon some inherent mysteries of the organism, considered with reference to its origin, maintains in contiguous regions a numerical relation between the species of various great families and the general mass of the phanerogamic plants constituting the two floras. We thus find a principle of unity and a primitive plan of distribution revealed in the multiplicity of the distinct organizations by which these regions are occupied; and we also discover in each zone, and diversified according to the families of plants, a slow but continuous action on the aerial ocean, depending upon the influence of light – the primary condition of all organic vitality – on the solid and liquid surface of our planet. It might be said, in accordance with a beautiful expression of Lavoisier, that the ancient marvel of the myth of Prometheus was incessantly renewed before our eyes.

If we extend the course which we have proposed, following in the exposition of the physical description of the earth to the sidereal part of the science of the Cosmos, the delineation of the regions of space and the bodies by which they are occupied, we shall find our task simplified in no common degree. If, according to ancient but unphilosophical forms of nomenclature, we would distinguish between physics, that is to say, general considerations on the essence of matter, and the forces by which it is actuated, and chemistry, which treats of the nature of substances, their elementary composition, and those attractions that are not determined solely by the relations of mass, we must admit that the description of the earth comprises at once physical and chemical actions. In addition to gravitation, which must be considered as a primitive force in nature, we observe that attractions of another kind are at work around us, both in the interior of our planet and on its surface. These forces, to which we apply the term chemical affinity, act upon molecules in contact, or at infinitely minute distances from one another,[22] and which, being differently modified by electricity, heat, condensation in porous bodies, or by the con-

[22]On the question already discussed by Newton, regarding the difference existing between the attraction of masses and molecular attraction, see Laplace, Exposition du Systéme du Monde, p. 384, and supplementto book x. of the Mecanique Céleste, p, 3, 4; Kant, Metaph. Agfangsgrinde der Naturwissenschaft, Sam. Werke, 1839, bd. v., s. 309 (Metaphysical Principles of the Nataral Sciences); Pectet, Physique, 1838.vol. i., p. 5963

tact of an intermediate substance, animate equally the inorganic world and animal and vegetable tissues. If we except the small asteroids, which appear to us under the forms of aérolites and shooting stars, the regions of space have hitherto presented to our direct observation physical phenomena alone; and in the case of these, we know only with certainty the effects depending upon the quantitative relations of matter or the distribution of masses. The phenomena of the regions of space may consequently be considered as influenced by simple dynamics laws - the laws of motion.

The effects that may arise from the specific difference and the heterogeneous nature of matter have not hitherto entered into our calculations of the mechanism of the heavens. The only means by which the inhabitants of our planet can enter into relation with the matter contained within the regions of space, whether existing in scattered forms or united into large spheroids, is by the phenomena of light, the propagation of luminous waves, and by the influence universally exercised by the force of gravitation or the attraction of masses. The existence of a periodical action of the sun and moon on the variations of terrestrial magnetism is even at the present day extremely problematical. We have no direct experimental knowledge regarding the properties and specific qualities of the masses circulating in space, or of the matter of which they are probably composed, if we except what may be derived from the fall of aérolites or meteoric stones, which, as we have already observed, enter within the limits of our terrestrial sphere. It will be sufficient here to remark, that the direction and the excessive velocity of projection (a velocity wholly planetary) manifested by these masses, render it more than probable that they are small celestial bodies, which, being attracted by our planet, are made to deviate from their original course, and thus reach the earth enveloped in vapors, and in a high state of actual incandescence. The familiar aspect of these asteroids, and the analogies which they present with the minerals composing the earth's crust, undoubtedly afford ample grounds for surprise;[23] but, in my opinion, the only conclusion to be drawn from these facts is, that, in general, planets and other sidereal

[23] [The analysis of an aérolite which fell a few years since in Maryland, United States, and was examined by Professor Silliman, of New Haven, Connecticut, gave the following results Oxyd of iron, 24; oxyd of nickel, 125; silica, with earthy matter, 346; sulphur, a trace2871. Dr. Mantells Wonders of Geology, 1848, vol.i., p. 51.J] – Tr.

masses, which, by the influence of a central body, have been agglomerated into rings of vapor, and subsequently into spheroids, being integrant parts of the same system, and having one common origin, may likewise be composed of substances chemically identical. Again, experiments with the pendulum, particularly those prosecuted with such rare precision by Bessel, confirm the Newtonian axiom, that bodies the most heterogeneous in their nature (as water, gold, quartz, granular limestone, and different masses of aérolites) experience a perfectly similar degree of acceleration from the attraction of the earth. To the experiments of the pendulum may be added the proofs furnished by purely astronomical observations. The almost perfect identity of the mass of Jupiter, deduced from the influence exercised by this stupendous planet on its own satellites, on Encke's comet of short period, and on the small planets Vesta, Juno, Ceres, and Pallas, indicates with equal certainty that within the limits of actual observation attraction is determined solely by the quantity of matter.[24]

This absence of any perceptible difference in the nature of matter, alike proved by direct observation and theoretical deductions, imparts a high degree of simplicity to the mechanism of the heavens. The immeasurable extent of the regions of space being subjected to laws of motion alone, the sidereal portion of the science of the Cosmos is based on the pure and abun-

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[24]Poisson, Connaissances des Temps pour l Année 1836, p. 6466.Bessel, Poggendorfs Annalen, bd. xxy.,s.417. Encke, Abhanalungender Berliner Academie (Trans. of the Berlin Academy), 1826, s. 217.Mitscherlich, Lehrbuch der Chemie (Manual of Chemistry), 1837 bd i.8. 352.

dant source of mathematical astronomy, as is the terrestrial portion on physics, chemistry, and organic morphology; but the domain of these three last-named sciences embraces the consideration of phenomena which are so complicated, and have, up to the present time, been found so little susceptible to the application of rigorous method, that the physical science of the earth cannot boast of the same certainty and simplicity in the exposition of facts and their mutual connection which characterize the celestial portion of the Cosmos. It is not improbable that the difference to which we allude may furnish an explanation of the cause which, in the earliest ages of intellectual culture among the Greeks, directed the natural philosophy of the Pythagoreans with more ardor to the heavenly bodies and the regions of space than to the earth and its productions, and how through Philolatis, and subsequently through the analogous views of Aristarchus of Samos, and of Seleucus of Erythrea, this science has been made more conducive to the attainment of a knowledge of the true system of the world than the natural philosophy of the Ionian school could ever be to the physical history of the earth. Giving but little attention to the properties and specific differences of matter filling space, the great Italian school, in its Doric gravity, turned by preference toward all that relates to measure, to the form of bodies, and to the number and distances of the planets,[25] while the Ionian physicists directed their attention to the qualities of matter, its true or supposed metamorphoses, and to relations of ori-

[25]Compare Otfried Millers Dorien, bd. i., 8. 365.

gin. It was reserved for the powerful genius of Aristotle, alike profoundly speculative and practical, to sound with equal success the depths of abstraction and the inexhaustible resources of vital activity pervading the material world.

Several highly distinguished treatises on physical geography are prefaced by an introduction, whose purely astronomical sections are directed to the consideration of the earth in its planetary dependence, and as constituting a part of that great system which is animated by one central body, the sun. This course is diametrically opposed to the one which I propose following. In order adequately to estimate the dignity of the Cosmos, it is requisite that the sidereal portion, termed by Kant the natural history of the heavens, should not be made subordinate to the terrestrial. In the science of the Cosmos, according to the expression of Aristarchus of Samos, the pioneer of the Copernican system, the sun, with its satellites, was nothing more than one of the innumerable stars by which space is occupied. The physical history of the world must, therefore, begin with the description of the heavenly bodies, and with a geographical sketch of the universe, or, I would rather say, a true map of the world, such as was traced by the bold hand of the elder Herschel. If, notwithstanding the smallness of our planet, the most considerable space and the most attentive consideration be here afforded to that which exclusively concerns it, this arises solely from the disproportion in the extent of our knowledge of that which is accessible and of that which is closed to our observation. This subordination of the celestial to the terrestrial portion is met with in the great work of Bernard Varenius, [26] which appeared in

[26] Geographia Generalis in qua affectiones generales telluris explicentur. The oldest Elzevir edition bears date 1650, the second 1672, and the third 1681; these were published at Cambridge, under Newton's supervision. This excellent work by Varenius is, in the true sense of the words, a physical description of the earth. Since the work Historia Natural de las Indias, 1590, in which the Jesuit Joseph de Acosta sketched in so masterly a manner the delineation of the New Continent, questions relating to the physical history of the earth have never been considered with such admirable generality. Acosta is richer in original observations, while Varenius embraces a wider circle of ideas, since his sojourn in Holland, which was at that period the center of vast commercial relations, had brought him in contact with a great number of well-informed travelers. Generalis sive Universalis Geographia dicitur que tellurem in genere considerat atque affectiones explicat, non habita particularium regionum ratione. The general description of the earth by Varenius (Pars Absoluta, cap. i.xxti.) may be considered as a treatise of comparative geography, if we adopt the term used by the author himself (Geographia Comparativa, cap. xxxiii.xl.), although this must be understood in a limited acceptation. We may cite the following among the most remarkable passages of this book: the enumeration of the systems of mountains; the examination of the relations existing between their directions and the general form of continents (p. 66, 76, ed. Cantab., 1681); a list of extinct volcanoes, and such as were

still in a state of activity; the discussion of facts relative to the general distribution of islands and archipelagoes (p. 220); the depth of the ocean relative to the height of neighboring coasts (p. 103); the uniformity of level observed in all open seas (p. 97); the dependence of currents on the prevailing winds; the unequal saltness of the sea; the configuration of shores (p. 139); the direction of the winds as the result of differences of temperature, etc. We may further instance the remarkable considerations of Varenius regarding the equinoctial current from east to west, to which he attributes the origin of the Gulf Stream, beginning at Cape St. Augustin, and issuing forth between Cuba and Florida (p. 140). Nothing can be more accurate than his description of the current which skirts the western coast of Africa, between Cape Verde and the island of Fernando Po in the Gulf of Guinea. Varenius explains the formation of sporadic islands by supposing them to be the raised bottom of the sea magna spirituum inclusorum vi, si ut aliquando montes e terra protusos esse quidam scribunt (p. 225). The edition published by Newton in 1681 (auctior et emendatior) unfortunately contains no additions from this great authority; and there was not even mention made of the polar compression of the globe, although the experiments on the pendulum by Richer had been made nine years prior to the appearance of the Cambridge edition. Newton's Principia Mathematica Philosophiæ Naturalis were not communicated in manuscript to the Royal Society until April, 1686. Much uncertainty seems to prevail regarding the birthplace of Varenius. Jächer says it was England, while, according to La Biographie Universelle (b. xlvii., p. 495), he is stated to have been born at Amsterdam; but it would appear, from the dedicatory address to the burgomaster of the middle of the seventeenth century. He was the first to distinguish between general and special geography, the former of which he subdivides into an absolute, or, properly speaking, terrestrial part, and a relative or planetary portion, according to the mode of considering our planet either with reference to its surface in its different zones, or to its relations to the sun and moon. It redounds to the glory of Varenius that his work on General and Compara-

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that city (see his Geographia Comparativa), that both suppositions are false. Varenius expressly says that he had sought refuge in Amsterdam, because his native city had been burned and completely destroyed during a long war, words which appear to apply to the north of Germany, and to the devastations of the Thirty Years War. In his dedication of another work, Descriptio regni Japoniæ (Amst., 1649), to the Senate of Hamburgh, Varenius says that he prosecuted his elementary mathematical studies in the gymnasium of that city. There is, therefore, every reason to believe that this admirable geographer was a native of Germany, and was probably born at Luneburg (Witten. Mem. Theol., 1685, p. 2142; Zedler, Universal Lexicon, vol. xlvi., 1745, p. 187).

tive Geography should in so high a degree have arrested the attention of Newton. The imperfect state of many of the auxiliary sciences from which this writer was obliged to draw his materials prevented his work from corresponding to the greatness of the design, and it was reserved for the present age, and for my own country, to see the delineation of comparative geography, drawn in its full extent, and in all its relations with the history of man, by the skillful hand of Carl Ritter.[27]

The enumeration of the most important results of the astronomical and physical sciences which in the history of theCosmos radiate.toward one common focus, may perhaps, to acertain degree, justify the des-

[27]Carl Ritter's Erdkundeim Verhältniss zur Natur und zur Geschichtedes Menschen, oder allgemeine vergleichende Geographie (Geography in relation to Nature and the History of Man, or general Comparative Geography).

ignation J have given to mywork, and, considered within the circumscribed limits I haveproposed to myself, the undertaking may be esteemed less adventurous than the title. The introduction of new terms, especially with reference to the general results of a science which ought to be accessible to all, has always been greatly in opposition to my own practice; and whenever I have enlargedupon the established nomenclature, it has only been in thespecialities of descriptive botany and zoology, where the 1ntroduction of hitherto unknown objects rendered new natnesnecessary. The denominations of physical descriptions of theuniverse, or physical cosmography, which I use indiscriminately, have been modeled upon those of physical descriptionsof the earth, that is to say, physical geography, terms thathave long been incommon use. Descartes, whose genius wasone of the most powerful manifested in any age, has left us afew fragments of a great work, which he intended publishingunder the title of Monde, and for which he had prepared himself by special studies, including even that of human anatomy.The uncommon, but definite expression of the science of theCosmos recalls to the mind of the inhabitant of the earth thatwe are treating of a more widelyextended horizonof theassemblage of all things with which space is filled, from theremotest nebulz to the climatic distribution of those delicatetissues of vegetable matter which spread a variegated covermg over the surface of our rocks.

The influence of narrow-minded views peculiar to the earlier ages of civilization led in all languages to a confusion of ideas in the synonymous use of the words earth and world, while the common expressions voyages round the world, map of the world, and new world, afford further illustrations of the same confusion. The more noble and precisely defined expressions of system of the world, the planetary world, and creation and age of the world, relate either to the totality of the substances by which space is filled, or to the origin of the whole universe.

It was natural that, in the midst of the extreme variability of phenomena presented by the surface of our globe, and the aerial ocean by which it is surrounded, man should have been impressed by the aspect of the vault of heaven, and the uniform and regular movements of the sun and planets. Thus the word Cosmos, which primitively, in the Homeric ages, indicated an idea of order and harmony, was subsequently adopted in scientific language, where it was gradually applied to the order observed in the movements of the heavenly bodies, to the whole universe, and then finally to the world in which this harmony was reflected to us. According to the assertion of Philolaus, whose fragmentary works have been so ably commented upon by Bockh, and conformably to the general testimony of antiquity, Pythagoras was the first who used the word Cosmos to designate the order that reigns in the universe, or entire world.[28]

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[28]Kéouoc, in the most ancient, and at the same time most precise, definition of the word, signified ornament (as an adornment for a man, woman, or a horse); taken figuratively for ebragia, it implied the order or adornment of a discourse. According to the testimony of all the ancients, it was Pythagoras who first used the word to designate the order in the universe, and the universe itself. Pythagoras left no writings; but ancient attestation to the truth of this assertion is to be found in several passages of the fragmentary works of Philo-

latis (Stob., Eclog., p. 360 and 460, Heeren), p. 62, 90, in Béckhs German edition, I do not, according to the example of Nike, cite Timzus of Locris, since his authenticity is doubtful. Plutarch (De plac. Phil., ii., 1) says, in the most express manner, that Pythagoras gave the name of Cosmos to the universe on account of the order which reigned throughout it; so likewise does Galen (Hist. Phil., p. 429). This word, together with its novel signification, passed from the schools of philosophy into the language of poets and prose writers. Plato designates the heavenly bodies by the name of Uranos, but the order pervading the regions of space he too terms the Cosmos, and in his Timeus (p. 30, B.) he says that the world is an animal endowed with a soul (kécpov Gaov éupiyov). Compare Anaxag. Claz., ed. Schaubach, p. 111, and Plut. (De plac. Phil., li, 3), on spirit apart from matter, as the ordaining power of nature. In Aristotle (De Calo, 1, 9), Cosmos signifies the universe and the order pervading it, but it is likewise considered as divided in space into two parts - the sublunary world, and the world above the moon. (Meteor., I., 2, 1, and I., 3, 13, p. 339, a, and 340, 4, Bekk.) The definition of Cosmos, which I have already cited, is taken from Pseudo-Aristoteles de Mundo, cap. ii. (p. 391); the passage referred to is as follows: Kéapoc éo7i otornua é obpabod Kai yc Kai TOv év Tov ToLe TeEpLExouévay gicewv. Aéyerat dé kat éxépuc xbadoc 7 Tay bAwy Tdétc Te Kaldraxdounotc, brd eGv te Kai did YeGv pudarrouévy. Most of the passages occurring in Greek writers on the word Cosmos may be found collected together in the controversy between Richard Bentley and Charles Boyle (Opuscula Philologica, 1781, p. 347, 445; Dissertation upon the Epistles of Phalaris, 1817, p. 254); on the historical existence of Zaleucus, legislator of Leucris, in, Nakes excellent work, Sched. Crit., 1812, p. 9, 15; and, finally, in Theophilus Schmidt, ad Cleom. Cycl. Theor., met. I., 1, p. ix., 1, and 99. Taken in a more limited sense, the word Cosmos is also used in the plural (Plut., 1, 5), either to designate the stars (Stob., 1, p. 514; Plut., 11, 13), or the innumerable systems scattered like islands through the immensity of space, and each composed of a sun and a moon. (Anax. Claz., Fragm., p. 89, 93, 120; Brandis, Gesch. der Griechisch-Rémischen Philosophie, b. i., 8. 252). Each of these groups forming thus a Cosmos, the universe, 76 wav, the word must be understood in a wider sense (Plut., ii., 1). It was not until long after the time of the Ptolemies that the word was applied to the earth. Béckh has made known inscriptions in praise of Trajan and Adrian (Corpus Inser. Grec., 1, n. 334 and 1036), in which Kéouoc occurs for oikovzevy, in the same manner as we still use the term world to signify the earth alone. We have already mentioned the singular division of the regions of space into three parts, the Olympus, Cosmos, and Ouranos (Stob., i., p. 488; Philolatis, p. 94, 202); this division applies to the different regions surrounding that mysterious focus of the universe, the Eorfa rov wavré, of the Pythagoreans. In the fragmentary passage in which this division is found, the term Ouranos designates the innermost region, situated between the moon and earth; this is the domain of changing things. The middle region, where the planets circulate in an invariable and harmonious order, is, in accordance with the special conceptions entertained of the universe, exclusively termed Cosmos, while the word Olympus is used to express the exterior or igneous region. Bopp, the profound philologist, has remarked, that we may deduce, as Potthas done, Etymol. Forschungen, th. i., s. 39 and

252, the word Kécyor from the Sanskrit root sud, purificari, by assuming two conditions; first, that the Greek in xéczo comes from the palatial , which Bopp represents by s and Ptt by (in the same manner as déxa, decem, taihun in Gothic, comes from the Indian word ddsan), and, next, that the Indian d corresponds, as a general rule, with the Greek 8 (Vergleichende Grammatik, 99 Comparative Grammar), which shows the relation of xéopog (for xdQz0) with the Sanskrit root sud, whence is also derived xaayéc. Another Indian term for the world is gagat (pronounced dschagat), which is, properly speaking, the present participle of the verb gagdmi (I go), the root of which is gd. In restricting ourselves to the circle of Hellenic etymologies, we find (Etymol. M., p. 532,12) that xéoyoe is intimately associated with Kdfw, or rather with xaivyyat, whence we have Kexacpévoc or xexaduévoc. Welcker (Eine Kretische Col. in Theben, 8. 23) combines with this the name Kddyoc, as in Hesychius xdduoc signifies a Cretan suit of arms. When the scientific language of Greece was introduced among the Romans, the word mundus, which at first had only the primary meaning of xéczoc (female ornament), was applied to designate the entire universe. Ennius seems to have been the first who ventured upon this innovation. In one of the fragments of this poet, preserved by Macrobius, on the occasion of his quarrel with Virgil, we find the word used in its novel mode of acceptation Mundus cali vastus constitit silentig (Sat., vi.,2). Cicero also says, Quem nos lucentem mundum vocamus (Timaxus, S. de Univer., cap. x.). The Sanskrit root mand, from which Pott derives the Latin mundus (Etym. Forsch., th. i., 8. 240), combines the double signification of shining and adorning. Léka designates in Sanskrit the world and people in general, in the same manner as

From the Italian school of philosophy, the expression passed, in this signification, into the language of those early poets of nature, Parmenides and Empedocles, and from thence into the works of prose writers. We will not here enter into a discussion of the manner in which, according to the Pythagorean views, Philolaus distinguishes between Olympus, Uranus, or the heavens, and Cosmos, or how the same word, used in a plural sense, could be ap-

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the French word monde, and is derived, according to Bopp, from 26k (to see and shine); it is the same with the Slavonic root swjet, which means both dight and world. The word welt, which the Germans make use of at the present day, and which was werait in old German, worold in old Saxon, and véruid in Ang'lo-Saxon, was, according to James Grimm's interpretation, a period of time, an age (seculum), rather than a term used for the world in space. The Etruscans figured to themselves mundus as an inverted dome, symmetrically opposed to the celestial vault (Otfried Miller's Etrusken, th. ii., 8. 96, c.). Taken in a still more limited sense, the word appears to have signified among the Goths the terrestrial surface girded by seas (mare, meri), the merigard, literally, garden of seas.

plied to certain heavenly bodies (the planets) revolving around one central focus of the world, or to groups of stars. In this work, I use the word Cosmos in conformity with the Hellenic usage of the term subsequently to the time of Pythagoras, and in accordance with the precise definition given of it in the treatise entitled De Mundo, which was long erroneously attributed to Aristotle. It is the assemblage of all things in heaven and earth, the universality of created things constituting the perceptible world. If scientific terms had not long been diverted from their true verbal signification, the present work ought rather to have borne the title of Cosmography, divided into Uranography and Geography. The Romans, in their feeble essays on philosophy, imitated the Greeks by applying to the universe the term mundus, which, in its primary meaning, indicated nothing more than ornament, and did not even imply order or regularity in the disposition of parts. It is probable that the introduction into the language of Latium of this technical term as an equivalent for Cosmos, in its double signification, is due to Ennius,[29] who was a follower of the Italian school, and the translator of the writings of Epicharmus and some of his pupils on the Pythagorean philosophy.

We would first distinguish between the physical history and the physical description of the world. The former, conceived in the most general sense of the word,

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[29]See, on Ennius, the ingenious researches of Leopold Krahner, in his Grundlinien zur Geschichte des Verfalls der Romischen Staats-Religion, 1837, s. 41-45 (Outlines of the History of the Decay of the Established Religion among the Romans). In all probability, Ennius did not quote from writings of Epicharmus himself, but from poems composed in the name of that philosopher, and in accordance with his views.

ought, if materials for writing it existed, to trace the variations experienced by the universe in the course of ages from the new stars which have suddenly appeared and disappeared in the vault of heaven, from nebulae dissolving or condensing to the first stratum of cryptogamic vegetation on the still imperfectly cooled surface of the earth, or on a reef of coral uplifted from the depths of the ocean. The physical description of the world presents a picture of all that exists in space, of the simultaneous action of natural forces, together with the phenomena which they produce.

But if we would correctly comprehend nature, we must not entirely or absolutely separate the consideration of the present state of things from that of the successive phases through which they have passed. We cannot form a just conception of their nature without looking back on the mode of their formation. It is not organic matter alone that is continually undergoing change, and being dissolved to form new combinations. The globe itself reveals at every phase of its existence the mystery of its former conditions.

We cannot survey the crust of our planet without recognizing the traces of the prior existence and destruction of an organic world. The sedimentary rocks present a succession of organic forms, associated in groups, which have successively displaced and succeeded each other. The different superimposed strata thus display to us the faunas and floras of different epochs. In this sense, the description of nature is intimately connected with its history; and the geologist, who is guided by the connection existing among the facts observed, cannot form a conception of the present without pursuing, through countless ages, the history of the past. In tracing the physical delineation of the globe, we behold the present and the past reciprocally incorporated, as it were, with one another; for the domain of nature is like that of languages, in which etymological research reveals a successive development, by showing us the primary condition of an idiom reflected in the form of speech in use at the present day. The study of the material world renders this reflection of the past peculiarly manifest, by displaying in the process of formation rocks of eruption and sedimentary strata similar to those of former ages. If I may be allowed to borrow a striking illustration from the geological relations by which the physiognomy of a country is determined, I would say that domes of trachyte, cones of basalt, lava streams (coulées) of amygdaloid with elongated and parallel pores, and white deposits of pumice, intermixed with black scoria, animate the scenery by the associations of the past which they awaken, acting upon the imagination of the enlightened observer like traditional records of an earlier world. Their form is their history.

The sense in which the Greeks and Romans originally employed the word istury proves that they too were intimately convinced that, to form a complete idea of the present state of the universe, it was necessary to consider it in its successive phases. It is not, however, in the definition given by Valerius Flaccus,[30] but in the zoological writings of Aristotle, that the word history presents itself as an exposition of the re-

[30] Aui. Gell., Noct. Até., v., 18.

sults of experience and observation. The physical description of the word by Pliny the elder bears the title of Natural History, while in the letters of his nephew it is designated by the nobler term of History of Nature. The earlier Greek historians did not separate the descriptions of countries from the narrative of events of which they had been the theater. With these writers, physical geography and history were long intimately associated, and remained simply but elegantly blended until the period of the development of political interests, when the agitation in which the lives of men were passed caused the geographical portion to be banished from the history of nations, and raised into an independent science.

It remains to be considered whether, by the operation of thought, we may hope to reduce the immense diversity of phenomena comprised by the Cosmos to the unity of a principle, and the evidence afforded by rational truths. In the present state of empirical knowledge, we can scarcely flatter ourselves with such a hope. Experimental sciences, based on the observation of the external world, cannot aspire to completeness; the nature of things, and the imperfection of our organs, are alike opposed to it. We shall never succeed in exhausting the immeasurable riches of nature; and no generation of men will ever have cause to boast of having comprehended the total aggregation of phenomena. It is only by distributing them into groups that we have been able, in the case of a few, to discover the empire of certain natural laws, grand and simple as nature itself. The extent of this empire will no doubt increase in proportion as physical sciences are more perfectly developed. Striking proofs of this advancement have been made manifest in our own day, in the phenomena of electromagnetism, the propagation of luminous waves and radiating heat. In the same manner, the fruitful doctrine of evolution shows us how, in organic development, all that is formed is sketched out beforehand, and how the tissues of vegetable and animal matter uniformly arise from the multiplication and transformation of cells.

The generalization of laws, which, being at first bounded by narrow limits, had been applied solely to isolated groups of phenomena, acquires in time more marked gradations, and gains in extent and certainty as long as the process of reasoning is applied strictly to analogous phenomena; but as soon as dynamical views prove insufficient where the specific properties and heterogeneous nature of matter come into play, it is to be feared that, by persisting in the pursuit of laws, we may find our course suddenly arrested by an impassable chasm. The principle of unity is lost sight of, and the guiding clew is rent asunder whenever any specific and peculiar kind of action manifests itself amid the active forces of nature. The law of equivalents and the numerical proportions of composition, so happily recognized by modern chemists, and proclaimed under the ancient form of atomic symbols, still remains isolated and independent of mathematical laws of motion and gravitation.

Those productions of nature which are objects of direct observation may be logically distributed in classes, orders, and families. This form of distribution undoubtedly sheds some light on descriptive natural history, but the study of organized bodies, considered in their linear connection, although it may impart a greater degree of unity and simplicity to the distribution of groups, cannot rise to the height of a classification based on one sole principle of composition and internal organization. As different gradations are presented by the laws of nature according to the extent of the horizon, or the limits of the phenomena to be considered, so there are likewise differently graduated phases in the investigation of the external world. Empiricism originates in isolated views, which are subsequently grouped according to their analogy or dissimilarity. To direct observation succeeds, although long afterward, the wish to prosecute experiments; that is to say, to evoke phenomena under different determined conditions. The rational experimentalist does not proceed at hazard, but acts under the guidance of hypotheses, founded on a half indistinct and more or less just intuition of the connection existing among natural objects or forces. That which has been conquered by observation or by means of experiments, leads, by analysis and induction, to the discovery of empirical laws. These are the phases in human intellect that have marked the different epochs in the life of nations, and by means of which that great mass of facts has been accumulated which constitutes at the present day the solid basis of the natural sciences.

Two forms of abstraction conjointly regulate our knowledge, namely, relations of quantity, comprising ideas of number and size, and relations of quality, embracing the consideration of the specific properties and the heterogeneous nature of matter. The former, as being more accessible to the exercise of thought, appertains to mathematics; the latter, from its apparent mysteries and greater difficulties, falls under the domain of the chemical sciences. In order to submit phenomena to calculation, recourse is had to a hypothetical construction of matter by a combination of molecules and atoms, whose number, form, position, and polarity determine, modify, or vary phenomena.

The mythical ideas long entertained of the imponderable substances and vital forces peculiar to each mode of organization have complicated our views generally and shed an uncertain light on the path we ought to pursue.

The most various forms of intuition have thus, age after age, aided in augmenting the prodigious mass of empirical knowledge, which in our own day has been enlarged with ever-increasing rapidity. The investigating spirit of man strives from time to time, with varying success, to break through those ancient forms and symbols invented to subject rebellious matter to rules of mechanical construction.

We are still very far from the time when it will be possible for us to reduce, by the operation of thought, all that we perceive by the senses, to the unity of a rational principle. It may even be doubted if such a victory could ever be achieved in the field of natural philosophy. The complication of phenomena and the vast extent of the Cosmos would seem to oppose such a result; but even a partial solution of the problem, the tendency toward a comprehension of the phenomena of the universe, will not the less remain the eternal and sublime aim of every investigation of nature.

In conformity with the character of my former writings, as well as with the labors in which I have been engaged during my scientific career, in measurements, experiments, and the verification of facts, I limit myself to the domain of empirical ideas.

The exposition of mutually connected facts does not exclude the classification of phenomena according to their rational connection, the generalization of many specialties in the great mass of observations, or the attempt to discover laws. Conceptions of the universe solely based upon reason, and the principles of speculative philosophy, would no doubt assign a still more exalted aim to the science of the Cosmos. I am far from blaming the efforts of others solely because their success has hitherto remained very doubtful. Contrary to the wishes and counsels of those profound and powerful thinkers who have given new life to speculations which were already familiar to the ancients, systems of natural philosophy have in our own country for some time past turned aside the minds of men from the graver study of mathematical and physical sciences. The abuse of better powers, which has led many of our noble but ill-judging youth into the saturnalia of a purely ideal science of nature, has been signalized by the intoxication of pretended conquests, by a novel and fantastically symbolical phraseology, and by a predilection for the formulas of a scholastic rationalism, more contracted in its views than any known to the Middle Ages. I use the expression "abuse of better powers" because superior intellects devoted to philosophical pursuits and experimental sciences have remained strangers to these saturnalia. The results yielded by an earnest investigation in the path of experiment cannot be at variance with a true philosophy of nature. If there be any contradiction, the fault must lie either in the unsoundness of speculation, or in the exaggerated pretensions of empiricism, which thinks that more is proved by experiment than is actually derivable from it.

External nature may be opposed to the intellectual world, as if the latter were not comprised within the limits of the former, or nature may be opposed to art when the latter is defined as a manifestation of the intellectual power of man; but these contrasts, which we find reflected in the most cultivated languages, must not lead us to separate the sphere of nature from that of mind, since such a separation would reduce the physical science of the world to a mere aggregation of empirical specialties. Science does not present itself to man until mind conquers matter in striving to subject the result of experimental investigation to rational combinations. Science is the labor of mind applied to nature, but the external world has no real existence for us beyond the image reflected within ourselves through the medium of the senses. As intelligence and forms of speech, thought and its verbal symbols, are united by secret and indissoluble links, so does the external world blend almost unconsciously to ourselves with our ideas and feelings. External phenomena, says Hegel, in his Philosophy of History, are in some degree translated in our inner representations. The objective world, conceived and reflected within us by thought, is subjected to the eternal and necessary conditions of our intellectual being. The activity of the mind exercises itself on the elements furnished to it by the perceptions of the senses. Thus, in the early ages of mankind, there manifests itself in the simple intuition of natural facts, and in the efforts made to comprehend them, the germ of the philosophy of nature. These ideal tendencies vary, and are more or less powerful, according to the individual characteristics and moral dispositions of nations, and to the degrees of their mental culture, whether attained amid scenes of nature that excite or chill the imagination.

History has preserved the record of the numerous attempts that have been made to form a rational conception of the whole world of phenomena, and to recognize in the universe the action of one sole active force by which matter is penetrated, transformed, and animated. These attempts are traced in classical antiquity in those treatises on the principles of things which emanated from the Ionian school, and in which all the phenomena of nature were subjected to hazardous speculations, based upon a small number of observations. By degrees, as the influence of great historical events has favored the development of every branch of science supported by observation, that ardor has cooled which formerly led men to seek the essential nature and connection of things by ideal construction and in purely rational principles. In recent times, the mathematical portion of natural philosophy has been most remarkably and admirably enlarged. The method and the instrument (analysis) have been simultaneously perfected. That which has been acquired by means so different by the ingenious application of atomic suppositions, by the more general and intimate study of phenomena, and by the improved construction of new apparatus is the common property of mankind, and should not, in our opinion, now, more than in ancient times, be withdrawn from the free exercise of speculative thought.

It cannot be denied that in this process of thought the results of experience have had to contend with many disadvantages; we must not, therefore, be surprised if, in the perpetual vicissitude of theoretical views, as is ingeniously expressed by the author of Gzordano Bruno,[31] most men see nothing in philosophy but a succession of passing meteors, while even the grander forms in which she has revealed herself share the fate of comets, bodies that do not rank in popular opinion among the eternal and permanent works of nature, but are regarded as mere fugitive apparitions of igncotsvapor. We would here remark that the abuse of thought, and the false track it too often pursues, ought not to sanction an opinion derogatory to intellect, which would imply that the domain of mind is essentially a world of vague fantastic illusions, and that the treasures accumulated by laborious observations in phi-

[31]Schellings Bruno, Ueber das Giéttliche und Naturaliche Princip.der Dinge, 181 (Bruno, on the Divine and Natural Principle of Things)

losophy are powers hostile to its own empire. It does not become the spirit which characterizes the present age distrustfully to reject every generalization of views and every attempt to examine into the nature of things by the process of reason and induction. It would be a denial of the dignity of human nature and the relative importance of the faculties with which we are endowed, were we to condemn at one time austere reason engaged in investigating causes and their mutual connections, and at another that exercise of the imagination which prompts and excites discoveries by its creative powers.

Chapter 2

Delineation of Nature. General Review of Natural Phenomena

When the human mind first attempts to subject to its control the world of physical phenomena, and strives by meditative contemplation to penetrate the rich luxuriance of living nature, and the mingled web of free and restricted natural forces, man feels himself raised to a height from whence, as he embraces the vast horizon, individual things blend together in varied groups, and appear as if shrouded in a vapory veil. These figurative expressions are used in order to illustrate the point of view from whence we would consider the universe both in its celestial and terrestrial sphere. I am not insensible of the boldness of such an undertaking. Among all the forms of exposition to which these pages are devoted, there is none more difficult than the general delineation of nature, which we purpose sketching, since we must not allow ourselves to be overpowered by a sense of the stupendous richness and variety of the forms presented to us, but must dwell only on the consideration of masses either possessing actual magnitude, or borrowing its semblance from the associations awakened within the subjective sphere of ideas. It is by a separation and classification of phenomena, by an intuitive insight into the play of obscure forces, and by animated expressions, in which the perceptible spectacle is reflected with vivid truthfulness, that we may hope to comprehend and describe the universal all (as may) in a manner worthy of the dignity of the word Cosmos in its signification of universe, order of the world, and adornment of this universal order. May the immeasurable diversity of phenomena which crowd into the picture of nature in no way detract from that harmonious impression of rest and unity which is the ultimate object of every literary or purely artistical composition.

Figure 2.1: Morning in the Tropics by Frederick Edwin Church. Public domain.

Beginning with the depths of space and the regions of remotest nebula, we will gradually descend through the starry zone to which our solar system belongs, to our own terrestrial spheroid, circled by air and ocean, there to direct our attention to its form, temperature, and magnetic tension, and to consider the fullness of organic life unfolding itself upon its surface beneath the vivifying influence of light. In this manner, a picture of the world may, with a few strokes, be made to include the realms of infinity no less than the minute microscopic animal and vegetable organisms which exist in standing waters and on the weatherbeaten surface of our rocks. All that can be perceived by the senses, and all that has been accumulated up to the present day by an attentive and variously directed study of nature, constitute the materials from which this representation is to be drawn, whose character is an evidence of its fidelity and truth. But the descriptive picture of nature which we purpose drawing must not enter too fully into detail, since a minute enumeration of all vital forms, natural objects, and processes is not requisite to the completeness of the undertaking. The delineator of nature must resist the tendency toward endless division, in order to avoid the dangers presented by the very abundance of our empirical knowledge. A considerable portion of the qualitative properties of matter or, to speak more in accordance with the language of natural philosophy, of the qualitative expression of forces is doubtlessly still unknown to us, and the attempt perfectly to represent unity in diversity must therefore necessarily prove unsuccessful. Thus, besides the pleasure derived from acquired knowledge, there lurks in the mind of man; and tinged with a shade of sadness, an unsatisfied longing for something beyond the present, a striving toward regions yet unknown and unopened. Such a sense of longing binds still faster the links which, in accordance with the supreme laws of our being, connect the material with the ideal world, and animates the mysterious relation existing between that which the mind receives from without, and that which it reflects from its own depths to the external world. If, then, nature (understanding by the term all natural objects and phenomena) be illimitable in extent and contents, it likewise presents itself to the human intellect as a problem which can not be grasped, and whose solution is impossible, since it requires a knowledge of the combined action of all natural forces. Such an acknowledgment is due where the actual state and prospective development of phenomena constitute the sole objects of direct investigation, which does not venture to depart from the strict rules of induction. But, although the incessant effort to embrace nature in its universality may remain unsatisfied, the history of the contemplation of the universe (which will be considered in another part of this work) will teach us how, in the course of ages, mankind has gradually attained to a partial insight into the relative dependence of phenomena. My duty is to depict the results of our knowledge in all their bearings with reference to the present. In all that is subject to motion and change in space, the ultimate aim, the very expression of physical laws, depend upon mean numerical values, which show us the constant amid change, and the stable amid apparent fluctuations of phenomena. Thus the progress of modern physical science is especially characterized by the attainment and the rectification of the mean values of certain quantities by means of the processes of weighing and measuring; and it may be said, that the only remaining and widely diffused hieroglyphic characters still in our writing numbers appear to us again, as powers of the Cosmos, although in a wider sense than that applied to them by the Italian School.

The earnest investigator delights in the simplicity of numerical relations, indicating the dimensions of the celestial regions, the magnitudes and periodical disturbances of the heavenly bodies, the triple elements of terrestrial magnetism, the mean pressure of the atmosphere, and the quantity of heat which the sun imparts in each year, and in every season of the year, to all points of the solid and liquid surface of our planet. These sources of enjoyment do not, however, satisfy the poet of Nature, or the mind of the inquiring many. To both of these, the present state of science appears as a blank, now that she answers doubtingly, or wholly rejects as unanswerable, questions to which former ages deemed they could furnish satisfactory replies. In her severer aspect, and clothed with less luxuriance, she shows herself deprived of that seductive charm with which a dogmatizing and symbolizing physical philosophy knew how to deceive the understanding and give the rein to imagination. Long before the discovery of the New World, it was believed that new lands in the Far West might be seen from the shores of the Canaries and the Azores. These illusive images were owing, not to any extraordinary refraction of the rays of light, but produced by an eager longing for the distant and the unattained. The philosophy of the Greeks, the physical views of the Middle Ages, and even those of a more recent period, have been eminently imbued with the charm springing from similar illusive phantoms of the imagination. At the limits of circumscribed knowledge, as from some lofty island shore, the eye delights to penetrate to distant regions. The belief in the uncommon and the wonderful lends a definite outline to every manifestation of ideal creation; and the realm of fancy – a fairyland of cosmological, geognostical, and magnetic visions – becomes thus involuntarily blended with the domain of reality.

Nature, in the manifold signification of the word – whether considered as the universality of all that is and ever will be, as the inner moving force of all phenomena, or as their mysterious prototype – reveals itself to the simple mind and feelings of man as something earthly and closely allied to himself. It is only within the animated circles of organic structure that we feel ourselves peculiarly at home. Thus, wherever the earth unfolds her fruits and flowers and gives food to countless tribes of animals, there the image of nature impresses itself most vividly upon our senses. The impression thus produced upon our minds limits itself almost exclusively to the reflection of the earthly. The starry vault and the wide expanse of the heavens belong to a picture of the universe in which the magnitude of masses, the number of congregated suns and faintly glimmering nebulae, although they excite our wonder and astonishment, manifest themselves to us in apparent isolation and as utterly devoid of all evidence of their being the scenes of organic life. Thus, even in the earliest physical views of mankind, heaven and earth have been separated and opposed to one another as an upper and lower portion of space. If, then, a picture of nature were to correspond to the requirements of contemplation by the senses, it ought to begin with a delineation of our native earth. It should depict, first, the terrestrial planet as to its size and form; its increasing density and heat at increasing depths in its superimposed solid and liquid strata; the separation of sea and land, and the vital forms animating both, developed in the cellular tissues of plants and animals; the atmospheric ocean, with its waves and currents, through which pierce the forest-crowned summits of our mountain chains. After this delineation of purely telluric relations, the eye would rise to the celestial regions, and the Earth would then, as the well-known seat of organic development, be considered as a planet, occupying a place in the series of those heavenly bodies which circle round one of the innumerable host of self-luminous stars. This succession of ideas indicates the course pursued in the earliest stages of perceptive contemplation and reminds us of the ancient conception of the sea-girt disk of earth, supporting the vault of heaven. It begins to exercise its action at the spot where it originated, and passes from the consideration of the known to the unknown, of the near to the distantIt corresponds with the method pursued in our elementary-works on astronomy (and which is so admirable in a mathematical point of view), of proceeding from the apparent to thereal movements of the heavenly bodies.

Chapter 3

Celestial Phenomena

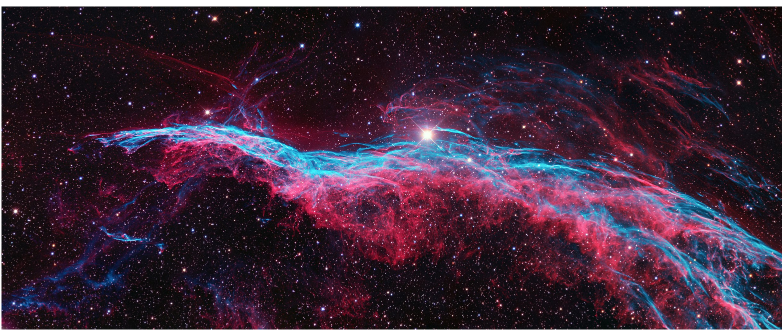

Figure 3.1: Image of the Veil Nebula. Author: Ken Crawford. License: CC BY-SA 3.0

Another course of ideas must, however, be pursued in a work which proposes merely to give an exposition of what is known, of what may in the present state of our knowledge be regarded as certain, or as merely probable in a greater or lesser degree, and does not enter into a consideration of the proofs on which such results have been based. Here, therefore, we do not proceed from the subjective point of view of human interests. The terrestrial must be treated only as a part, subject to the whole. The view of nature ought to be grand and free, uninfluenced by motives of proximity, social sympathy, or relative utility. A physical cosmography - a picture of the universe - does not begin, therefore, with the terrestrial, but with that which fills the regions of space. But as the sphere of contemplation contracts in dimension, our perception of the richness of individual parts, the fullness of physical phenomena, and of the heterogeneous properties of matter becomes enlarged. From the regions in which we recognize only the dominion of the laws of attraction, we descend to our own planet, and to the intricate play of terrestrial forces. The method here described for the delineation of nature is opposed to that which must be pursued in establishing conclusive results. The one enumerates what the other demonstrates.

Man learns to know the external world through the organs of the senses. Phenomena of light proclaim the existence of matter in remotest space, and the eye is thus made the medium through which we may contemplate the universe. The discovery of telescopic vision more than two centuries ago has transmitted to the latest generations a power whose limits are as yet unattained.

The first and most general consideration in the Cosmos is that of the contents of space – the distribution of matter, or of creation, as we are wont to designate the assemblage of all that is and ever will be developed. We see matter either agglomerated into rotating, revolving spheres of different density and size, or scattered through space in the form of self-luminous vapor. If we consider first the cosmical vapor dispersed in definite nebulous spots, its state of aggregation will appear constantly to vary, sometimes appearing separated into round or elliptical disks, single or in pairs, occasionally connected by a thread of light;

while, at another time, these nebulæ occur in forms of larger dimensions, and are either elongated, or variously branched, or fan-shaped, or appear like well-defined rings, enclosing a dark interior. It is conjectured that these bodies are undergoing variously developed formative processes, as the cosmical vapor becomes condensed in conformity with the laws of attraction, either round one or more of the nuclei. Between two and three thousand of such unresolvable nebulæ, in which the most powerful telescopes have hitherto been unable to distinguish the presence of stars, have been counted, and their positions determined.

The genetic evolution – that perpetual state of development which seems to affect this portion of the regions of space - has led philosophical observers to the discovery of the analogy existing among organic phenomena. As in our forests we see the same kind of tree in all the various stages of its growth, and are thus enabled to form an idea of progressive, vital development, so do we also,

Figure 3.2: Anaximenes of Miletus was an Ancient Greek, Pre-Socratic philosopher from Miletus in Anatolia. He was the last of the three philosophers of the Milesian School, after Thales and Anaximander. Source: Wikimedia Commons.

in the great garden of the universe, recognize the most different phases of sidereal formation. The process of condensation, which formed a part of the doctrines of Anaximenes and of the Ionian School, appears to be going on before our eyes. This subject of investigation and conjecture is especially attractive to the imagination, for in the study of the animated circles of nature, and of the action of all the moving forces of the universe, the charm that exercises the most powerful influence on the mind is derived less from a knowledge of that which is than from a perception of that which will be, even though the latter be nothing more than a new condition of a known material existence; for actual creation, of origin, the beginning of existence from non-existence, we have no experience, and can therefore form no conception.

A comparison of the various causes influencing the development manifested by the greater or less degree of condensation in the interior of nebulæ, no less than a successive course of direct observations, has led to the belief that changes of form have been recognized first in Andromeda, next in the constellation Argo, and in the isolated filamentous portion of the nebula in Orion. But the want of uniformity in the power of the instruments employed, different conditions of our atmosphere, and other optical relations, render a part of the results invalid as historical evidence.

Nebulous stars must not be confounded either with irregularly shaped nebulous spots, properly so called, whose separate parts have an unequal degree of brightness (and which may, perhaps, become concentrated into stars as their circumference contracts), nor with the so-called planetary nebulæ, whose circular or slightly oval disks manifest in all their parts a perfectly uniform thezres of faint light. Nebulous stars are not merely accidental bodies projected upon a nebulous ground, but are a part of the nebulous matter constituting one mass with the body which it surrounds. The not unfrequently considerable magnitude of their apparent diameter, and the remote distance from which they are revealed to us, show that both the planetary nebulæ and the nebulous stars must be of enormous dimensions. New and ingenious considerations of the different influence exercised by distance[1] on

[1]The optical considerations relative to the difference presented by a single luminous point, and by a disk subtending an appreciable angle, in which the intensity of light is constant at every distance, are explained in Arago's Analyse des Travaux de Sir William Herschel

the intensity of light of a disk of appreciable diameter, and of a single self-luminous point, render it not improbable that the planetary nebulæ are very remote nebulous stars, in which the difference between the central body and the surrounding nebulous covering can no longer be detected by our telescopic instruments.

The magnificent zones of the southern heavens, between 50° and 80°, are especially rich in nebulous stars and in compressed unresolvable nebulæ. The larger of the two Magellanic clouds, which circle round the starless, desert pole of the south, appears, according to the most recent researches,[2] as a collection of clus-

(Annuaire du Bureau des Long., 1842, p. 410-412, and 441).

[2]The two Magellanic clouds, Nubecula major and Nubecula minor, are very remarkable objects. The larger of the two is an accumulated mass of stars, and consists of clusters of stars of irregular form, either conical masses or nebulæ of different magnitudes and

ters of stars, composed of globular clusters and nebulæ of different magnitudes, and of large nebulous spots not resolvable which, producing a general brightness in the field of view, form, as it were, the background of the picture. The appearance of these clouds, of the brightly beaming constellation Argo, of the Milky Way between Scorpio, the Centaur, and the Southern Cross, the picturesque beauty, if one may so speak, of the whole expanse of the southern celestial hemisphere, has left upon my mind an ineffaceable impression.

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degrees of condensation. This is interspersed with nebulous spots, not resolvable into stars, but which are probably star dust, appearing only as a general radiance upon the telescopic field of a twenty-feet reflector, and forming a luminous ground on which other objects of striking and indescribable form are scattered. In no other portion of the heavens are so many nebulous and stellar masses thronged together in an equally small space. Nubecula minor is much less beautiful, has more unresolvable nebulous light, while the stellar masses are fewer and fainter in intensity. (From a letter of Sir John Herschel, Feldhuysen, Cape of Good Hope, 13th June, 1836.)

The zodiacal light, which rises in a pyramidal form, and constantly contributes, by its mild radiance, to the external beauty of the tropical nights, is either a vast nebulous ring, rotating between the Earth and Mars, or, less probably, the exterior stratum of the solar atmosphere. Besides these luminous clouds and nebulæ of definite form, exact and corresponding observations indicate the existence and the general distribution of an apparently nonluminous, infinitely divided matter, which possesses a force of resistance, and manifests its presence in Encke's, and perhaps also in Biela's comet, by diminishing their eccentricity and shortening their period of revolution. Of this impeding, ethereal, and cosmical matter, it may be supposed that it is in motion; that it gravitates, notwithstanding its original tenuity; that it is condensed in the vicinity of the great mass of the Sun; and, finally, that it may, for myriads of ages, have been augmented by the vapor emanating from the tails of comets.

If we now pass from the consideration of the vaporous matter of the immeasurable regions of space (ὀυρανοῦ χόρος)[3] – whether, scattered without definite form

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[3]Should have made use, in the place of garden of the universe, of the beautiful expression χόρος ὀυρανοῦ, borrowed by Hesychius from an unknown poet, if χόρος had not rather signified in general an enclosed space. The connection with the German garten and the English garden, gards in Gothic (derived, according to Jacob Grimm, from gairdan, to gird), is, however, evident, as is likewise the affinity with the Slavonic grad, gorod, and as Pott remarks, in his Etymol. Forschungen, th. i., s. 144 (Etymol. Researches), with the Latin chors, whence we have the Spanish corte, the French cour, and the English word court, together with the Ossetic khart. To these may be further added the Scandinavian gard, gdrd, a place enclosed, as a court, or a country seat, and the Persian gerd, gird, a district, a circle, a princely country seat, a castle or city, as we find the term applied to the names of places in Firdusi's Schahnameh, as Siyawakschgird, Darabgird, c.

[This word is written gaard in the Danish.] – Tr.

and limits, it exists as a cosmical ether, or is condensed into nebulous spots, and becomes comprised among the solid agglomerated bodies of the universe, we approach a class of phenomena exclusively designated by the term of stars, or as the sidereal world.

Here, toc, we find differences existing in the solidity or density of the spheroidally agglomerated matter. Our own solar system presents all stages of mean density (or of the relation of volume to mass.) On comparing the planets from Mercury to Mars with the Sun and with Jupiter, and these two last named with the yet inferior density of Saturn, we arrive, by a descending scale to draw our illustration from terrestrial substances at the respective densities of antimony, honey, water, and pine wood. In comets, which actually constitute the most considerable portion of our solar system with respect to the number of individual forms, the concentrated part, usually termed the head, or nucleus, transmits sidereal light unimpaired. The mass of a comet probably in no case equals the five thousandth part of that of the earth, so dissimilar are the formative processes manifested in the original and perhaps still progressive agglomerations of matter. In proceeding from general to special considerations, it was particularly desirable to draw attention to this diversity, not merely as a possible, but as an actually proved fact.

Figure 3.3: Frederick William Herschel was a German-British astronomer and composer. Source: Wikimedia Commons.

The purely speculative conclusions arrived at by Wright, Kant, and Lambert, concerning the general structural arrangement of the universe, and of the distribution of matter in space, have been confirmed by Sir William Herschel, on the more certain path of observation and measurement. That great and enthusiastic, although cautious observer, was the first to sound the depths of heaven in order to determine the limits and form of the starry stratum which we inhabit, and he, too, was the first who ventured to throw the light of investigation upon the relations existing between the position and distance of remote nebula and our own portion of the sidereal universe. William Herschel, as is well expressed in the elegant inscription on his monument at Upton, broke through the enclosures of heaven (calorum perrupit claustra), and, like another Columbus, penetrated into an unknown ocean, from which he beheld coasts and groups of islands, whose true position it remains for future ages to determine.

Considerations regarding the different intensity of light in stars, and their relative number, that is to say, their numerical frequency on telescopic fields of equal magnitude, have led to the assumption of unequal distances and distribution in space in the strata which they compose. Such assumptions, in as far as they may lead us to draw the limits of the individual portions of the universe, cannot offer the same degree of mathematical certainty as that which may be attained in all that relates to our solar system, whether we consider the rotation of double stars with unequal velocity around one common center of gravity, or the apparent or true movements of all the heavenly bodies. If we take up the physical description of the universe from the remotest nebula, we may be inclined to compare it with the mythical portions of history. The one begins in the obscurity of antiquity, the other in that of inaccessible space; and at the point where reality seems to flee before us, imagination becomes doubly incited to draw from its own fullness, and give definite outline and permanence to the changing forms of objects.

If we compare the regions of the universe with one of the island-studded seas of our own planet, we may imagine matter to be distributed in groups, either as unresolvable nebula of different ages, condensed around one or more nuclei, or as already agglomerated into clusters of stars, or isolated spheroidal bodies. The cluster of stars, to which our cosmical island belongs, forms a lens-shaped, flattened stratum, detached on every side, whose major axis is estimated at seven or eight hundred, and its minor one at a hundred and fifty times the distance of Sirius. It would appear, on the supposition that the parallax of Sirius is not greater than that accurately determined for the brightest star in the Centaur (0″.9128), that light traverses one distance of Sirius in three years, while it also follows, from Bessel's earlier excellent Memoir[4]" on the parallax of the remarkable star 61 Cygni (0".3483), (whose considerable motion might lead to the inference of great proximity), that a period of nine years and a quarter is required for the transmission of light from this star to our planet. Our starry stratum is a

[4]See Maclear's Results from 1839 to 1840, in the Trans. of the Astronomical Soc., vol. xii., p. 370, on a Centauri, the probable mean error being 00640. For 61 Cygni, see Bessel, in Schumacher's Jahbuch, 1839, s. 47, and Schumacher's Astron. Nachr., bd. xviii., s. 401, 402, probable mean error, 00141. With reference to the relative distances of stars of different magnitudes, how those of the third magnitude may probably be three times more remote, and the manner in which we represent to ourselves the material arrangement of the starry strata, I have found the following remarkable passage in Kepler's Epitome Astronomia Copernicane, 1618, t. i., lib. 1, p. 3439: "Solhic noster nil aliud est quam una ex fizis, nobis major et clarior visa, quia propior quam fiza. Pone terram stare ad latus, una semidiametravie lactee, tune hec via lactea apparebit circulus parvus, vel ellipsis parva, tota declinans ad latus alterum; eritque simul uno intuitu conspicua, que nune non potest nisi dimidia conspici quovis momento. Itaque fixerum sphera non tantum orbe stellarum, sed etiam cireulo lactis veraus nos deorsum est terminata.

disk of inconsiderable thickness, divided a third of its length into two branches; it is supposed that we are near this division, and nearer to the region of Sirius than to the constellation Aquila, almost in the middle of the stratum in the line of its thickness or minor axis.

Chapter 4

Sidereal Systems

This position of our solar system, and the form of the whole discoidal stratum, have been inferred from sidereal scales, that is to say, from that method of counting the stars to which I have already alluded, and which is based upon the equidistant subdivision of the telescopic field of view. The relative depth of the stratum in all directions is measured by the greater or smaller number of stars appearing in each division. These divisions give the length of the ray of vision in the same manner as we measure the depth to which the plummet has been thrown, before it reaches the bottom, although in the case of a starry stratum there can not, correctly speaking, be any idea of depth, but merely of outer limits. In the direction of the longer axis, where the stars lie behind one another, the more remote ones appear closely crowded together, united, as it were, by a milky white radiance or luminous vapor, and are perspectively grouped, encircling, as in a zone, the visible vault of heaven. This narrow and branched girdle, studded with radiant light, and here and there interrupted by dark spots, deviates only by a few degrees from forming a perfect large circle round the concave sphere of heaven, owing to our being near the center of the large starry cluster, and almost on the plane of the Milky Way. If our planetary system were far outside this cluster, the Milky Way would appear to telescopic vision as a ring, and at a still greater distance as a resolvable discoidal nebula.

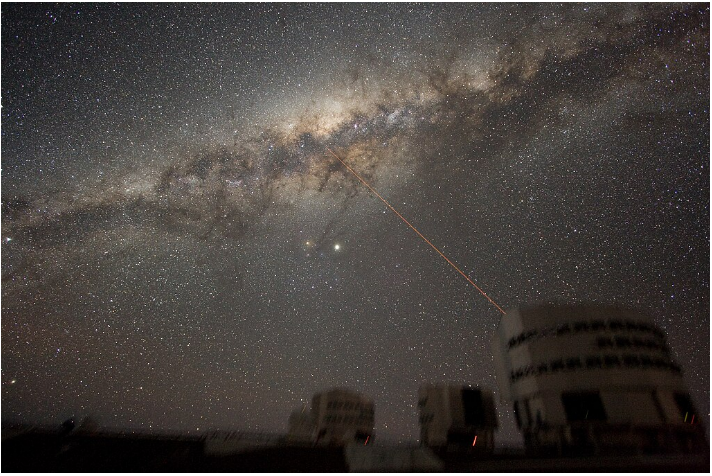

Figure 4.1: The Galactic Center as seen from Earth's night sky (featuring the telescope's laser guide star). Listed below is Galactic Center's information. Author: ESO/Y. Beletsky. License: CC BY 4.0.

Among the many self-luminous moving suns, erroneously called fixed stars, which constitute our cosmical island, our own sun is the only one known by direct observation to be a central body in its relations to spherical agglomerations of matter directly depending upon and revolving round it, either in the form of planets, comets, or aërolite asteroids. As far as we have hitherto been able to investigate multiple stars (double stars or suns), these bodies are not subject, with respect to relative motion and illumination, to the same planetary dependence that characterizes our own solar system. Two or more self-luminous bodies, whose planets and moon, if such exist, have hitherto escaped our telescopic powers of vision, certainly revolve around one common center of gravity; but this is in a portion of space which is probably occupied merely by unagglomerated matter or cosmical vapor, while in our system the center of gravity is often comprised within the innermost limits of a visible central body. If, therefore, we regard the Sun and the Earth, or the Earth and the Moon, as double stars, and the whole of our planetary solar system as a multiple cluster of stars, the analogy thus suggested must be limited to the universality of the laws of attraction in different systems, being alike applicable to the independent processes of light and to the method of illumination.

For the generalization of cosmical views, corresponding with the plan we have proposed to follow in giving a delineation of nature or of the universe, the solar system to which the Earth belongs may be considered in a twofold relation first, with respect to the different classes of individually agglomerated matter, and the relative size, conformation, density, and distance of the heavenly bodies of this system; and, secondly, with reference to other portions of our starry cluster, and of the changes of position of its central body, the Sun.

Chapter 5

Planetary Systems

The solar system, that is to say, the variously formed matter circling round the Sun, consists, according to the present state of our knowledge, of eleven primary planets,[1] eighteen satellites or secondary plan-

[1] [Since the publication of Baron Humboldt's work in 1845, several other planets have been discovered, making the number of those

belonging to our planetary system sixteen instead of eleven. Of these, Astrea, Hebe, Flora, and Iris are members of the remarkable group of asteroids between Mars and Jupiter. Astrea and Hebe were discovered by Hencke at Driesen, the one in 1846 and the other in 1847; Flora and Iris were both discovered in 1847 by Mr. Hind, at the South Villa Observatory, Regents Park. It would appear from the latest determinations of their elements, that the small planets have the following order with respect to mean distance from the Sun: Flora, Iris, Vesta, Hebe, Astrea, Juno, Ceres, Pallas. Of these, Flora has the shortest teens (about 34 years). The planet Neptune, which, after having been predicted by several astronomers, was actually observed on the 25th of September, 1846, is situated on the confines of our planetary system beyond Uranus. The discovery of this planet is not only highly interesting from the importance attached to it as a question of science, but also from the evidence it affords of the care and unremitting labor evinced by modern astronomers in the investigation and comparison of the older calculations, and the ingenious application of the results thus obtained to the observation of new facts. The merit of having paved the way for the discovery of the planet Neptune is due to M. Bouvard, who, in his persevering and assiduous efforts to deduce the entire orbit of Uranus from observations made during the forty years that succeeded the discovery of that planet in 1781, found the results yielded by theory to be at variance with fact, in a degree that had no parallel in the history of astronomy. This startling discrepancy, which seemed only to gain additional weight from every attempt made by M. Bouvard to correct his calculations, led Leverrier, after a careful modification of the tables of Bouvard, to establish the proposition that there was a formal incompatibility between the observed motions of Uranus and the hypothesis that he was acted on only by the Sun and known planets, according to the law of universal gravitation. Pursuing this idea, Leverrier arrived at the conclusion that the disturbing cause must be a planet, and, finally, after an amount of labor that seems perfectly overwhelming, he, on the 31st of August, 1846, laid before the French Institute a paper, in which he indicated the exact spot in the heavens where this new planetary body would be found, giving the following data for its various elements mean distance from the Sun, 36154 times that of the Earth; period of revolution, 217387 years; mean long., Jan. Ist, 1847, 3189 47; mass, gy55th; heliocentric long., Jan. Ist, 1847, 326 32. Essential difficulties still intervened, however, and as the remoteness of the planet rendered it improbable that its disk would be discernible by any telescopic instrument, no other means remained for detecting the suspected body but its planetary motion, which could only be ascertained by mapping, after every observation, the quarter of the heavens scanned, and by a comparison of the various maps. Fortunately for the verification of Leverrier's predictions, Dr. Bremiker had just completed a map of the precise region in which it was expected the new planet would appear, this being one of a series of maps made for the Academy of Berlin, of the small stars along the entire zodiac. By means of this valuable assistance, Dr. Galle, of the Berlin Observatory, was led, on the 25th of September, 1846, by the discovery of a star of the eighth magnitude, not recorded in Dr. Bremiker's map, to make the first observation of the planet predicted by Leverrier. By a singular coincidence, Mr. Adams, of Cambridge, had predicted the appearance of the planet simultaneously with M. Leverrier; but by the concur-ets, and myriads of comets, three ofwhich, known as the planetary comets, do not pass beyondthe narrow limits of the orbits described by the principalplanets. We may, with no inconsiderable degree of probability, include within the domain of our Sun, in the immediate sphere of its central force, a rotating ring of vaporous

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rence of several circumstances much to be regretted, the world at large were not made acquainted with Mr. Adams's valuable discovery until subsequently to the period at which Leverrier published his observations. As the data of Leverrier and Adams stand at present, there is a discrepancy between the predicted and the true distance, and in some other elements of the planet; it remains, therefore, for these or future astronomers to reconcile theory with fact, or perhaps, as in the case of Uranus, to make the new planet the means of leading to yet greater discoveries. It would appear from the most recent observations, that the mass of Neptune, instead of being, as at first stated, 5,',,th, is only about sg) yah that of the Sun, while its periodic time is now given with a greater probability at 166 years, and its mean distance from the Sun nearly 30. The planet appears to have a ring, but as yet no accurate observations have been made regarding its system of satellites. See Trans. Astrau. Soc., and The Planet Neptune, 1848, by J. P. Nicholl.]

matter, lying probably between the orbits of Venus and Mars, butcertainly beyond that of the Earth,[2] which appears to us in a pyramidal form, and is known as the Zodiacal Light ; and a host of very small asteroids, whose orbits either intersect, orvery nearly approach, that of our earth, and which present uswith the phenomena of aérolites and falling or shooting starsWhen we consider the complication of variouslyformed bodieswhich revolve round the Sun in orbits of such dissimilar eccentricityalthough we may not

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[2]"If there should be molecules in the zones diffused by the atmosphere of the Sun of too volatile a nature either to combine with one another or with the planets, we must suppose that they would, in circling round that luminary, present all the appearances of zodiacal light,without opposing any appreciable resistance to the different bodies composing the planetary system, either owing to their extreme rarity, orto the similarity existing between their motion and that of the planetswith which they come in contact.Laplace, Expos. du Syst. du Monde(ed. 5), p. 415.

be disposed, with the immortal author of the Mécanique Céleste, to regard the largernumber of comets as nebulous stars, passing from one centralsystem to another,[3] we yet can not fail to acknowledge thatthe planetary systern, especially so called (that is, the groupof heavenly bodies which, together with their satellites, revolve with but slightly eccentric orbits round the Sun), constitutes but a small portion of the whole system with respectto individual numbers, if not to mass.

It has been proposed to consider the telescopic planets, Vesta, Juno, Ceres, and Pallas, with their more closely intersecting, inclined, and eccentric orbits, as a zone of separation, oras a middle group in space; and if this view be adopted, weshall discover that the interior planetary

[3]Laplace, Exp. du Syst. du Monde, p. 396, 414.

group (consisting ofMercury, Venus, the Earth, and Mars) presents several very striking contrasts[4] when compared with the exterior group,comprising Jupiter, Saturn, and Uranus. The planets nearest the Sun, and consequently included in the inner group, areof more moderate size, denser, rotate more slowly and withnearly equal velocity (their periods of revolution being almostall about 24 hours), are less compressed at the poles, and, with-the exception of one, are without satellites. The exteriorplanets, which are further removed from the Sun, are veryconsiderably larger, have a density five times less, more thantwice as great a velocity in the period of their rotation roundtheir axes, are more compressed at the poles, and if six satel-

[4]Littrow, Astronomie, 1825, bd. xi., 107. Midler Astron., 1841, 212. Laplace, Ezp. de Syst. du Monde, p. 210.

lites may be ascribed to Uranus, have a quantitative preponderance in the number of their attendant moons, which is as seventeen to one.

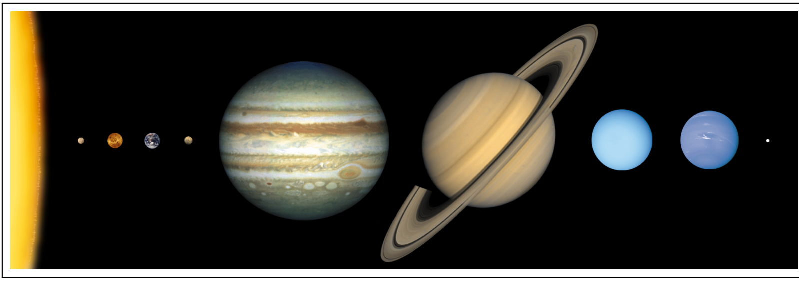

Figure 5.1: Approximate sizes of the planets of our solar system relative to each other. Outward from the Sun, the planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. The planets are not shown at the appropriate distance from the Sun. Author: Lunar and Planetary Laboratory. Public Domain.

Such general considerations regarding certain characteristic properties appertaining to whole groups cannot, however, be applied with equal justice to the individual planets of every group, nor to the relations between the distances of the revolving planets from the central body, and their absolute size, density, period of rotation, eccentricity, and the inclination of their orbits and the axes. We know as yet of no inherent necessity, no mechanical natural law, similar to the one which teaches us that the squares of the periodic times are proportional to the cubes of the major axes, by which the above-named six elements of the planetary bodies and the form of their orbit are made dependent either on one another or on their mean distance from the Sun. Mars is smaller than the Earth and Venus, although further removed from the Sun than these last-named planets, approaching most nearly in size to Mercury, the nearest planet to the Sun. Saturn is smaller than Jupiter, and yet much larger than Uranus. The zone of the telescopic planets, which have so inconsiderable a volume, immediately precedes Jupiter (the greatest in size of any of the planetary bodies), if we consider them with regard to distance from the Sun; and yet the disks of these small asteroids, which scarcely admit of measurement, have an areal surface not much more than half that of France, Madagascar, or Borneo. However striking may be the extremely small density of all the colossal planets, which are furthest removed from the Sun, we are yet unable in this respect to recognize any regular succession.[5] Uranus appears to be denser than

[5]See Kepler, on the increasing density and volume of the planets in proportion with their increase of distance from the Sun, which is described as the densest of all the heavenly bodies; in the Epitome Astron. Copern. in vii. libros digesta, 1618-1622, p. 420. Leibnitz also inclined to the opinions of Kepler and Otto von Guericke, that the planets increase in volume in proportion to their increase of distance from the Sun. See his letter to the Magdeburg Burgomas-

Saturn, even if we adopt the smaller mass, $\frac{1}{24005}$, assumed by Lamont; and, notwithstanding the inconsiderable difference of density observed in the innermost planetary group,[6] we find both Venus and Mars less dense than the Earth, which lies between them. The time of rotation certainly diminishes with increasing solar distance, but yet it is greater in Mars than in the Earth, and in Saturn than in Jupiter. The elliptic orbits of Juno, Pallas, and Mercury have the greatest degree of eccentricity, and Mars and Venus, which immediately follow each other, have the least. Mercury and Venus exhibit the same contrasts that may be observed in the four smaller planets, or asteroids, whose paths are so closely

ter (Mayence, 1672) in Leibnitz, Deutschen Schriften, herausg. von Guhrauer, th. i., 264.

[6]On the arrangement of masses, see Encke, in Schum., Asér. Nachr, 1843 Nr. 488, 114.

interwoven.

The eccentricities of Juno and Pallas are very nearly identical, and are each three times as great as those of Ceres and Vesta. The same may be said of the inclination of the orbits of the planets toward the plane of projection of the ecliptic, or in the position of their axes of rotation with relation to their orbits, a position on which the relations of climate, seasons of the year, and length of the days depend more than on eccentricity. Those planets that have the most elongated elliptic orbits, as Juno, Pallas, and Mercury, have also, although not to the same degree, their orbits most strongly inclined toward the ecliptic. Pallas has a comet-like inclination nearly twenty-six times greater than that of Jupiter, while in the little planet Vesta, which is so near Pallas, the angle of inclination scarcely by six times exceeds that of Jupiter. An equally irregular succession is observed in the position of the axes of the few planets (four or five) whose planes of rotation we know with any degree of certainty. It would appear from the position of the satellites of Uranus, two of which, the second and fourth, have been recently observed with certainty, that the axis of this, the outermost of all the planets, is scarcely inclined as much as 11 toward the plane of its orbit, while Saturn is placed between this planet, whose axis almost coincides with the plane of its orbit, and Jupiter, whose axis of rotation is nearly perpendicular to it.

In this enumeration of the forms which compose the world in space, we have delineated them as possessing an actual existence, and not as objects of intellectual contemplation, or as mere links of a mental and causal chain of connection. The planetary system, in its relations of absolute size and relative position of the axes, density, time of rotation, and different degrees of eccentricity of the orbits, does not appear to offer to our apprehension any stronger evidence of a natural necessity than the proportion observed in the distribution of land and water on the Earth, the configuration of continents, or the height of mountain chains. In these respects, we can discover no common law in the regions of space or in the inequalities of the earth's crust. They are facts in nature that have arisen from the conflict of manifold forces acting under unknown conditions, although man considers as accidental whatever he is unable to explain in the planetary formation on purely genetic principles. If the planets have been formed out of separate rings of vaporous matter revolving round the Sun, we may conjecture that the different thickness, unequal density, temperature, and electro-magnetic tension of these rings may have given occasion to the most various agglomerations of matter, in the same manner as the amount of tangential velocity and small variations in its direction have produced so great a difference in the forms and inclinations of the elliptic orbits. Attractions of mass and laws of gravitation have no doubt exercised an influence here, no less than in the geognostic relations of the elevations of continents; but we are unable from present forms to draw any conclusions regarding the series of conditions through which they have passed. Even the so-called law of the distances of the planets from the Sun, the law of progression (which led Kepler to conjecture the existence of a planet supplying the link that was wanting in the chain of connection between Mars and Jupiter), has been found numerically inexact for the distances between Mercury, Venus, and the Earth, and at variance with the conception of a series, owing to the necessity for a supposition in the case of the first member. The hitherto discovered principal planets that revolve round our Sun are attended certainly by fourteen, and probably by eighteen secondary planets (moons or satellites). The principal planets are, therefore, themselves the central bodies of subordinate systems. We seem to recognize in the fabric of the universe the same process of arrangement so frequently exhibited in the development of organic life, where we find in the manifold combinations of groups of plants or animals the same typical form repeated in the subordinate classes. The secondary planets or satellites are more frequent in the external region of the planetary system, lying beyond the intersecting orbits of the smaller planets or asteroids; in the inner region none of the planets are attended by satellites, with the exception of the Earth, whose moon is relatively of great magnitude, since its diameter is equal to a fourth of that of the Earth, while the diameter of the largest of all known secondary planets, the sixth satellite of Saturn, is probably about one seventeenth, and the largest of Jupiter's moons, the third, only about one twenty-sixth part that of the primary planet or central body. The planets which are attended by the largest number of satellites are most remote from the Sun and are at the same time the largest, most compressed at the poles, and the least dense. According to the most recent measurements of Madler, Uranus has a greater planetary compression than any other of the planets, viz., 544d. In our Earth and her moon, whose mean distance from one another amounts to 207,200 miles, we find that the differences of mass[7] and diameter between the two are much less considerable than are usually observed to exist between the principal planets and their attendant satellites, or between bodies of dif-

[7]If, according to Burckhardts determination, the Moon's radius be 0.2725 and its volume „4„th, its density will be 05596, or nearly five ninths. Compare, also, Wilh. Beer und H. Madler, der Mond, 2,10, and Madler, Asz., 157. The material contents of the Moon are, according to Hausen, nearly 1th (and according to Madler ,.,th) that of the Earth, and its mass equal to;,4,d that of the Earth. In the largest of Jupiter's moons, the third, the relations of volume to the central body are sty ath, and of mass 5,4„th. On the polar flattening of Uranus, see Schum., Astron. Nachr., 1844, No, 493.

ferent orders in the solar system. While the density of the Moon is five ninths less than that of the Earth, it would appear, if we may sufficiently depend upon the determinations of their magnitudes and masses, that the second of Jupiter's moons is actually denser than that great planet itself. Among the fourteen satellites that have been investigated with any degree of certainty, the system of the seven satellites of Saturn presents an instance of the greatest possible contrast, both in absolute magnitude and in distance from the central body. The sixth of these satellites is probably not much smaller than Mars, while our moon has a diameter which does not amount to more than half that of the latter planet. With respect to volume, the two outer, the sixth and seventh of Saturn's satellites, approach the nearest to the third and brightest of Jupiter's moons. The two innermost of these satellites belong perhaps, together with the remote moons of Uranus, to the smallest cosmical bodies of our solar system, being only made visible under favorable circumstances by the most powerful instruments. They were first discovered by the forty-foot telescope of William Herschel in 1789, and were seen again by John Herschel at the Cape of Good Hope, by Vico at Rome, and by Lamont at Munich. Determinations of the true diameter of satellites, made by the measurement of the apparent size of their small disks, are subjected to many optical difficulties; but numerical astronomy, whose task it is to predetermine by calculation the motions of the heavenly bodies as they will appear when viewed from the Earth, is directed almost exelusively to motion and mass, and but little to volume.The absolute distance of a satellite from its central body isgreatest in the case of the outermost or seventh satellite ofSaturn, its distance from the body round which it revolvesamounting to more than two millions of miles, or ten times asgreat a distance as that of our moon from the Earth. In thecase of Jupiter we find that the outermost or fourth attendantmoon is only 1,040,000 miles from that planet, while the distance between Uranus and its sixth satellite (if the latter really exist) amounts to as much as 1,360,000 miles. If we compare, in each of these subordinate systems, the volume of themain planet with the distance of the orbit of its most remotesatellite, we discover the existence of entirely new numericalrelations. The distances of the outermost satellites of Uranus,Saturn, and Jupiter are, when expressed in semidiametersof the main planets, as 91, 64, and 27. The outermost satellite of Saturn appears, therefore, to be removed only aboutone fifteenth further from the center of that planet than ourmoon is from the Earth. The first or innermost of Saturnssatellites is nearer to its central body than ayy other of thesecondary planets, and presents, moreover, the only instanceof a period of revolution of less than twentyfour hours. Itsdistance from the center of Saturn may, according to Madlerand Wilhelm Beer, be expressed as 247 semidiameters of thatplanet, or as 80,088 miles. Its distance from the surface ofthe main planet is therefore 47,480 miles, and from the outermost edge of the ring only 4916 miles. The traveler mayform to himself an estimate of the smallness of this amountby remembering the statement of an enterprising navigator,Captain

Beechey, that he had in three years passe over 72,800miles. If, instead of absolute distances, we take the semidiameters of the principal planets, we shall find that even thefirst or nearest of the moons of Jupiter (which is 26,000 milesfurther removed from the center of that planet than our moonis from that of the Earth) is only six semidiameters of Jupiterfrom its center, while our moon is removed from us fully 603dsemidiameters of the Earth.

In the subordinate systems of satellites, we find that the same laws of gravitation which regulate the revolutions of the principal planets round the Sun likewise govern the mutual relations existing between these planets among one another and with reference to their attendant satellites. The twelve moons of Saturn, Jupiter, and the Earth all move like the primary planets from west to east, and in elliptic orbits, deviating but little from circles. It is only in the case of one moon, and perhaps in that of the first and innermost of the satellites of Saturn (0068), that we discover an eccentricity greater than that of Jupiter; according to the very exact observations of Bessel, the eccentricity of the sixth of Saturn's satellites (0029) exceeds that of the Earth. On the extreme limits of the planetary system, where, at a distance nineteen times greater than that of our Earth, the centripetal force of the Sun is greatly diminished, the satellites of Uranus (which have certainly been but imperfectly investigated) exhibit the most striking contrasts from the facts observed with regard to other secondary planets. Instead, as in all other satellites, of having their orbits but slightly inclined toward the ecliptic and (not excepting even Saturn's ring, which may be regarded as a fusion of agglomerated satellites) moving from west to east, the satellites of Uranus are almost perpendicular to the ecliptic, and move retrogressively from east to west, as Sir John Herschel has proved by observations continued during many years. If the primary and secondary planets have been formed by the condensation of rotating rings of solar and planetary atmospheric vapor, there must have existed singular causes of retardation or impediment in the vaporous rings revolving round Uranus, by which, under relations with which we are unacquainted, the revolution of the second and fourth of its satellites was made to assume a direction opposite to that of the rotation of the central planet.

Chapter 6

Comets

It seems highly probable that the period of rotation of all secondary planets is equal to that of their revolution round the main planet, and therefore that they always present to the latter the same side. Inequalities, occasioned by slight variations in the revolution, give rise to fluc-

Figure 6.1: Comet Kohoutek (C/1973 E1). Author: NASA. Public domain.

tuations of from 6 to 8, or to an apparent libration in longitude as well as in latitude. Thus, in the case of our moon, we sometimes observe more than half of its surface, with the eastern and northern edges being more visible at one time, and the western or southern at another. By means of this libration[1] we are enabled to see the annular mountain Malapert (which occasionally conceals the Moon's south pole), the arctic landscape round the crater of Gioja, and the large gray plain near Endymion, which exceeds in superficial extent the Mare Vaporum. Three sevenths of the Moon's surface are entirely concealed from our observation, and must always remain so, unless new and unexpected disturbing causes come into play. These cosmical relations involuntarily remind us of nearly similar conditions in the intellectual world, where, in the domain of deep research into the mysteries and the primeval creative forces of nature, there are regions similarly turned away from us, and apparently unattainable, of

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[1] Beer and Madler, op. cit., 185, s. 208, and 347, 8 332; and in their Phys. Kenntniss der himml. Kérper, s. 4 und 69, Tab. 1 (Physical History of the Heavenly Bodies).

which only a narrow margin has revealed itself, for thousands of years, to the human mind, appearing, from time to time, either glimmering in true or delusive light. We have hitherto considered the primary planets, their satellites, and the concentric rings which belong to one, at least, of the outermost planets, as products of tangential force, and as closely connected together by mutual attraction. It therefore now only remains for us to speak of the unnumbered host of comets which constitute a portion of the cosmical bodies revolving in independent orbits round the Sun. If we assume an equable distribution of their orbits, and the limits of their perihelia, or greatest proximities to the Sun, and the possibility of their remaining invisible to the inhabitants of the Earth, and base our estimates on the rules of the calculus of probabilities, we shall obtain as the result an amount of myriads perfectly astonishing. Kepler, with his usual animation of expression, said that there were more comets in the regions of space than fishes in the depths of the ocean. As yet, however, there are scarcely one hundred and fifty whose paths have been calculated, if we may assume at six or seven hundred the number of comets whose appearance and passage through known constellations have been ascertained by more or less precise observations. While the so-called classical nations of the West, the Greeks and Romans, although they may occasionally have indicated the position in which a comet first appeared, never afford any information regarding its apparent path, the copious literature of the Chinese (who observed nature carefully, and recorded with accuracy what they saw) contains circumstantial notices of the constellations through which each comet was observed to pass. These notices go back to more than five hundred years before the Christian era, and many of them are still found to be of value in astronomical observations.[2]

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[2]The first comets of whose orbits we have any knowledge, and which were calculated from Chinese observations, are those of 240 (under Gordian III.), 539 (under Justinian), 565, 568, 574, 837, 1337, and 1385. See John Russell Hind, in Schum., Astron. Nachr., 1843, No. 498. While the comet of 837 (which, according to Du Séjour, continued during twenty-four hours within a distance of 2,000,000 miles from the Earth) terrified Louis I. of France to that degree that he busied himself in building churches and Saati monastic establishments, in the hope of appeasing the evils threatened by its appearance, the Chinese astronomers made observations on the path of this cosmical body, whose tail extended over a space of 60, appearing sometimes single and sometimes multiple. The first comet that has been calculated solely from European observations was that of 1456, known as Halley's comet, from the belief long, but erroneously, entertained that the period when it was first observed by that astronomer was its first and only well-attested appearance. See Arago, in the Annuaire, 1836, p. 204, and Laugier, Comptes Rendus

Although comets have a smaller mass than any other cosmical bodiesbeing, according to our present knowledge, probably not equal to s3;5th part of the Earths massyet theyoccupy the largest space, as their tails ia several instances extend over many millions of miles. The cone of luminous vapor which radiates from them has been found, in some eases in 1680 and 1811), to equal the length of the Earth's distance from the Sun, forming a line that intersects both theorbits of Venus and Mercury. It is even probable that thevapor of the tails of comets mingled with our atmosphere inthe years 1819 and 1823.

Comets exhibit such diversities of form, which appear rather to appertain to the individual than the class, that a description of one of these wandering light clouds, as

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des Séances de l'Acad., 1843, t. xvi., 1006.

they were already called by Xenophanes and Theon of Alexandria, contemporaries of Pappus, can only be applied with caution to another. The faintest telescopic comets are generally devoid of visible tails and resemble Herschel's nebulous stars. They appear like circular nebulae of faintly glimmering vapor, with the light concentrated toward the middle. This is the most simple type, but it cannot, however, be regarded as rudimentary since it might equally be the type of an older cosmical body, exhausted by exhalation. In the larger comets, we may distinguish both the so-called head or nucleus and the single or multiple tail, which is characteristically denominated by the Chinese astronomers as the brush (szz). The nucleus generally presents no definite outline, although, in a few rare cases, it appears like a star of the first or second magnitude and has even been seen in bright sunshine;[3] as, for instance, in the large comets of 1402, 1532, 1577, 1744, and 1843. This latter circumstance indicates, in particular individuals, a denser mass, capable of reflecting light with greater intensity. Even in Herschel's large telescope, only two comets, that discovered in Sicily in 1807 and the splendid one of 1811, exhibited well-defined disks;[4]

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[3]Arago, Annuaire, 1832, p. 209, 211. The phenomenon of the tail of a comet being visible in bright sunshine, which is recorded of the comet of 1402, occurred again in the case of the large comet of 1843, whose nucleus and tail were seen in North America on the 28th of February (according to the testimony of J. G. Clarke, of Portland, state of Maine), between 1 and 3 o'clock in the afternoon. The distance of the very dense nucleus from the sun's light admitted of being measured with much exactness. The nucleus and tail appeared like a very pure white cloud, a darker space intervening between the tail and the nucleus. (Amer. Journ. of Science, vol. xlv., No. 1, p. 229.)

[4]Phil. Trans. for 1808, Part ii., p. 155, and for 1812, Part i., p. 118.The diameters found by Herschel for the nuclei were 538 and 428 English miles. For the magnitudes of the comets of 1798 and

the one at an angle of 1, and the other at 0.77, whence the true diameters are assumed to be 536 and 428 miles. The diameters of the less well-defined nuclei of the comets of 1798 and 1805 did not appear to exceed 24 or 28 miles.

In several comets that have been investigated with great care, especially in the above-named one of 1811, which continued visible for so long a period, the nucleus and its nebulous envelope were entirely separated from the tail by a darker space. The intensity of light in the nucleus of comets does not augment toward the center in any uniform degree, brightly shining zones being in many cases sep-

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1805, seeArago, Annuaire, 1832, p. 203.

[The translator was at New Bedford, Massachusetts, U.S., on the 28th Februry, 1843, and distinctly saw the comet, between and 2 in the afternoon. The sky at the time was intensely blue, and the sun shining with a dazzling brightness unknown in Europeas climates.] – Tr.

arated by concentric nebulous envelopes. The tails sometimes appear single, sometimes, although more rarely, double; and in the comets of 1807 and 1843, the branches were of different lengths; in one instance (1744), the tail had six branches, the whole forming an angle of 60. The tails have been sometimes straight, sometimes curved, either toward both sides or toward the side appearing to us as the exterior (as in 1811), or convex toward the direction in which the comet is moving (as in that of 1618); and sometimes the tail has even appeared like a flame in motion. The tails are always turned away from the sun, so that their line of prolongation passes through its center; a fact which, according to Edward Biot, was noticed by the Chinese astronomers as early as 837 but was first generally made known in Europe by Fracastoro and Peter Apian in the sixteenth century. These emanations may be regarded as conoidal envelopes of greater or less thickness, and, considered in this manner, they furnish a simple explanation of many of the remarkable optical phenomena already spoken of.

Comets are not only characteristically different in form, some being entirely without a visible tail, while others have a tail of immense length (as in the instance of the comet of 1618, whose tail measured 104), but we also see the same comets undergoing successive and rapidly changing processes of configuration. These variations of form have been most accurately and admirably described in the comet of 1744, by Hlensius, at St. Petersburg, and in Halley's comet, on its last reappearance in 1835, by Bessel, at Konigsberg. A more or less well-defined tuft of rays emanated from that part of the nucleus which was turned toward the Sun; and the rays being bent backward, formed a part of the tail. The nucleus of Halley's comet, with its emanations, presented the appearance of a burning rocket, the end of which was turned sideways by the force of the wind. The rays issuing from the head were seen by Arago and myself, at the Observatory at Paris, to assume very different forms on successive nights.[5] The great Konigsberg astronomer concluded from many measurements, and from theoretical considerations, that the cone of light issuing from the comet deviated considerably both to the right and the left of the true direc-

[5] Arago, Des Changements physiques de la Comète de Halley du 1523 Oct., 1835. Annuaire, 1836, p. 218, 221. The ordinary direction of the emanations was noticed even in Nero's time. Come radios eos effugiunt. Seneca, Nat. Quest., vii., 20.

tion of the Sun, but that it always returned to that direction, and passed over to the opposite side, so that both the cone of light and the body of the comet from whence it emanated experienced a rotatory, or, rather, a vibratory motion in the plane of the orbit. He finds that the attractive force exercised by the Sun on heavy bodies is inadequate to explain such vibrations, and is of the opinion that they indicate a polar force, which turns one semidiameter of the comet toward the Sun, and strives to turn the opposite side away from that luminary. The magnetic polarity possessed by the Earth may present some analogy to this, and, should the Sun have an opposite polarity, an influence might be manifested, resulting in the precession of the equinoxes. This is not the place to enter more fully upon the grounds on which explanations of this subject have been based; but observations so remarkable,[6] and views of so exalted character, regarding the most wonderful class of the cosmical bodies belonging to our solar system, ought not to be entirely passed over in this sketch of a general picture of nature.

Although, as a rule, the tails of comets increase in magnitude and brilliance in the vicinity of the sun, and are directed away from that central body, yet the comet of 1823 offered the remarkable example of two tails, one of which was turned toward the sun, and the other away from it, forming with each other an angle of 160. Modi-

[6]Bessel, in Schumacher, Astr. Nachr., 1836, No. 300-302, s. 188, 192, 197, 200, 202, und 230. Also in Schumacher, Jahrb., 1837, s. 149, 168.William Herschel, in his observations on the beautiful comet of 1811,believed that he had discovered evidences of the rotation of the nucleusand tail (Pail. Trans. for 1812, Parti., p. 140). Dunlop, at Paramatla, thought the same with reference to the third comet of 1825.

fications of polarity and the unequal manner of its distribution, and of the direction in which it is conducted, may in this rare instance have occasioned a double, unchecked, continuous emanation of nebulous matter.[7]

Aristotle, in his Natural Philosophy, makes these emanations the means of bringing the phenomena of comets into a singular connection with the existence of the Milky Way. According to his views, the innumerable quantity of stars which compose this starry zone give out a self-luminous, incandescent matter. The nebulous belt which separates the different portions of the vault of heaven was therefore regarded by the Stagirite as a large comet, the substance of which was incessantly be-

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[7]Bessel, in Astr. Nachr., 1836, No. 302, s. 231. Schum., Jahrb., 1837, s. 175. See, also, Lehmann, Ueber Cometenschweife (On the Tails of Comets), in Bode, Astron. Jahrb. far 1826, s. 168.

ing renewed.[8]

The occultation of the fixed stars by the nucleus of a comet, or by its innermost va-

[8] Aristot., Meteor., i., 8, 1114, und 1921 (ed. Ideler, t. i., p. 3234). Biese, Phil. des Aristoteles, bd. ii., s. 86. Since Aristotle exercised so great an influence throughout the whole of the Middle Ages, it is very much to be regretted that he was so averse to those grander views of the elder Pythagoreans, which inculcated ideas so nearly approximating to truth respecting the structure of the universe. He asserts that comets are transitory meteors belonging to our atmosphere in the very book in which he cites the opinion of the Pythagorean school, according to which these cosmical bodies are supposed to be planets having long periods of revolution. (Aristot., i., 6, 2.) This Pythagorean doctrine, which, according to the testimony of Apollonius Myndius, was still more ancient, having originated with the Chaldeans, passed over to the Romans, who in this instance, as was their usual practice, were merely the copiers of others. The Myndian philosopher describes the path of comets as directed toward the upper and remote regions of heaven. Hence Seneca says, in his Nat. Quest., vii., 17 "Cometes non est species falsa, sed proprium sidus sicut solis et lune altiora mundi secat et tunc demum apparet quum in imum cursum sui venit; and again (at vi'., 27), "Cometes aternos esse et sortis ejusdem, cujus cetera (sidera), etiamsi faciem illis non habent similem." Pliny (ii., 25) also refers to Apollonius Myndius, when he says, "Sunt qui et hec sidera perpetua esse credant suoque ambitu ire, sed non nisi relicta a sole cerni."

porous envelopes, might throw some light on the physical character of these wonderful bodies; but we are unfortunately deficient in observations by which we may be assured[9] that the occultation was perfectly central; for, as it has already been observed, the parts of the envelope contiguous to the nucleus are alternately com-

[9]Olbers, in Astr. Nachr., 1828, s. 157, 184. Arago, De la Constitution physique des Comètes; Annuaire de 1832, p. 203, 208. The ancients were struck by the phenomenon that it was possible to see through comets as through a flame. The earliest evidence to be met with of stars having been seen through comets is that of Democritus (Aristot., Meteor., i., 6, 11), and the statement leads Aristotle to make the not unimportant remark, that he himself had observed the occultation of one of the stars of Gemini by Jupiter. Seneca only speaks devidedly of the transparency of the tail of comets. We may see, says he, stars through a comet as through a cloud (Nat. Quest., vii., 18); but we can only see through the rays of the tail, and not through the body of the comet itself zon in ea parte qua sidus ipsum est spissi et solidi ignis, sed qua rarus splendor occurrit et in crines dispergitur. Per intervalla ignium, non per ipsos, vides (vii., 26). The last remark is unnecessary, since, as Galileo observed in the Saggiatore (Lettera a Monsignor Cesarini, 1619), we can certainly see through a flame when it is not of too great a thickness.

posed of layers of dense or very attenuated vapor. On the other hand, the carefully conducted measurements of Bessel prove, beyond all doubt, that on the 29th of September, 1835, the light of a star of the tenth magnitude, which was then at a distance of 778 from the central point of the head of Halley's comet, passed through very dense nebulous matter, without experiencing any deflection during its passage.[10] If such an absence of refracting power must be ascribed to the nucleus of a comet, we can scarcely regard the matter composing comets as a gaseous fluid.

[10]Bessel, in the Astron. Nachr., 1836, No. 301, s. 204, 206. Struve, in Recueil des Mémoires de Acad. de St. Petersb., 1836, p. 140, 143, and Astr. Nachr., 1836, No. 303, s. 238, writes as follows: "At Dorpat the star was in conjunction only 22 from the brightest point of the comet. The star remained continually visible, and its light was not perceptibly diminished, while the nucleus of the comet seemed to be almost extinct before the radiance of the small star of the ninth or tenth magnitude."

The question here arises whether this absence of refracting power may not be owing to the extreme tenuity of the fluid; or does the comet consist of separated particles, constituting a cosmical stratum of clouds, which, like the clouds of our atmosphere, that exercise no influence on the zenith distance of the stars, does not affect the ray of light passing through it? In the passage of a comet over a star, a more or less considerable diminution of light has often been observed; but this has been justly ascribed to the brightness of the ground from which the star seems to stand forth during the passage of the comet.

The most important and decisive observations that we possess on the nature and the light of comets are due to Arago's polarization experiments. His polariscope instructs us regarding the physical constitution of the Sun and comets, indicating whether a ray that reaches us from a distance of many millions of miles transmits light directly or by reflection; and if the former, whether the source of light is a solid, a liquid, or a gaseous body. His apparatus was used at the Paris Observatory in examining the light of Capella and that of the great comet of 1819. The latter showed polarized, and therefore reflected light, while the fixed star, as was to be expected, appeared to be a self-luminous sun.[11] The

[11] On the 3rd of July, 1819, Arago made the first attempt to analyze the light of comets by polarization, on the evening of the sudden appearance of the great comet. I was present at the Paris Observatory, and was fully convinced, as were also Matthieu and the late Bouvard, of the dissimilarity in the intensity of the light seen in the polariscope, when the instrument received cometary light. When it received light from Capella, which was near the comet, and at an equal altitude, the images were of equal intensity. On the reappearance of Halley's comet in 1835, the instrument was altered so as to give, according to Arago's chromatic polarization, two images of complementary colors (green and red). (Annales de Chimie, t. xill.,

existence of polarized cometary light announced itself not only by the inequality of the images, but was proved with greater certainty on the reappearance of Halley's comet, in the year 1835, by the more striking contrast of the complementary colors, deduced from the laws of chromatic polarization discovered by Arago in 1811. These beautiful experiments still leave it undecided whether, in addition to this reflected solar light, comets may not have light of their own. Even in the case of the planets, as, for instance, in Venus, an evolution of independent light seems very probable.

The variable intensity of light in comets

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p.108; Annuaire, 1832, p. 216.) We must conclude from these observations, says Arago, that the cometary light was not entirely composed of rays having the properties of direct light, there being light which was reflected specularly or polarized, that is, coming from the sun. It can not be stated with absolute certainty that comets shine only with borrowed light, for bodies, in becoming self-luminous, do not, on that account, lose the power of reflecting foreign light.

cannot always be explained by the position of their orbits and their distance from the Sun. It would seem to indicate, in some individuals, the existence of an inherent process of condensation, and an increased or diminished capacity of reflecting borrowed light. In the comet of 1618, and in that which has a period of three years, it was observed first by Hevelius that the nucleus of the comet diminished at its perihelion and enlarged at its aphelion, a fact which, after remaining long unheeded, was again noticed by the talented astronomer Valz at Nimes. The regularity of the change of volume, according to the different degrees of distance from the Sun, appears very striking. The physical explanation of the phenomenon cannot, however, be sought in the condensed layers of cosmical vapor occurring in the vicinity of the Sun, since it is difficult to imagine the nebulous envelope of the nucleus of the comet to be vesicular and impervious to the ether.[12]

The dissimilar eccentricity of the orbits of comets has, in recent times (1819), in the most brilliant manner enriched our knowledge of the solar system. Encke has discovered the existence of a comet of so short a period of revolution that it remains entirely within the limits of our planetary system, attaining its aphelion between the orbits of the smaller planets and that of Jupiter. Its eccentricity must be assumed at 0.845, that of Juno (which has the greatest eccentricity of any of the planets) being 0.255. Encke's comet has several times, although with difficulty, been observed by the naked eye, as in Europe in 1819, and,

[12] Arago, in the Annuaire, 1832, p. 217-220. Sir John Herschel, Astron., 488.

according to Rümker, in New Holland in 1822. Its period of revolution is about 3.1 years; but, from a careful comparison of the epochs of its return to its perihelion, the remarkable fact has been discovered that these periods have diminished in the most regular manner between the years 1786 and 1838, the diminution amounting, in the course of 52 years, to about 1/4th days. The attempt to bring into unison the results of observation and calculation in the investigation of all the planetary disturbances, with the view of explaining this phenomenon, has led to the adoption of the very probable hypothesis that there exists dispersed in space a vaporous substance capable of acting as a resisting medium. This matter diminishes the tangential force, and with it the major axis of the comet's orbit. The value of the constant of the resistance appears to be somewhat different before and after the perihelion; and this may, perhaps, be ascribed to the altered form of the small nebulous star in the vicinity of the Sun, and to the action of the unequal density of the strata of cosmical ether.[13] These facts, and the investigations to which they have led, belong to the most interesting results of modern astronomy. Encke's comet has been the means of leading astronomers to a more exact investigation of Jupiter's mass (a most important point with reference to the calculation of perturbations); and, more recently, the source of this comet has obtained for us the first determination, although only an approximate one, of a smaller mass for Mercury.

[13]Encke, in the Astronomische Nachrichten, 1843, No. 489, s. 130132.

The discovery of Encke's comet, which had a period of only 31 years, was speedily followed, in 1826, by that of another, Biela's comet, whose period of revolution is 6.3 years, and which is likewise planetary, having its aphelion beyond the orbit of Jupiter, but within that of Saturn. It has a fainter light than Encke's comet, and, like the latter, its motion is direct, while Halley's comet moves in a course opposite to that pursued by the planets. Biela's comet presents the first certain example of the orbit of a comet intersecting that of the Earth. This position, with reference to our planet, may therefore be productive of danger, if we can associate an idea of danger with so extraordinary a natural phenomenon, whose history presents no parallel, and the results of which we are consequently unable correctly to estimate.

Small masses endowed with enormous velocity may certainly exercise a considerable power; but Laplace has shown that the mass of the comet of 1770 is probably not equal to 1/25th of that of the Earth, estimating further with apparent correctness the mean mass of comets as much below 1/557th that of the Earth, or about 1/75th that of the Moon.[14] We must not confound the passage of Biela's comet through the Earth's orbit with its proximity to, or collision with, our globe. When this passage took place, on the 29th of October, 1832, it required a full month before the Earth would reach the point of intersection of the two orbits. These two comets of short periods of revolution also intersect each other, and it has been justly observed,[15] that amid the many perturba-

[14] Laplace, Expos. du Syst. du Monde, p. 216, 237.

[15] Littrow, Beschreibende Astron., 1835, s. 274. On the inner comet

tions experienced by such small bodies from the larger planets, there is a possibility, supposing a meeting of these comets to occur in October, that the inhabitants of the Earth may witness the extraordinary spectacle of an encounter between two cosmical bodies, and possibly of their reciprocal penetration and amalgamation, or of their destruction by means of exhausting emanations. Events of this nature, resulting either from deflection occasioned by disturbing masses or primevally intersecting orbits, must have been of frequent occurrence in the course of millions of years in the immeasurable regions of ethereal

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recently discovered by M. Faye, at the Observatory of Paris, and whose eccentricity is 0.551, its distance at its perihelion 1.690, and its distance at its aphelion 5.832, see Schumacher, Astron. Nachr., 1844, No. 495. Regarding the supposed identity of the comet of 1766 with the third comet of 1819, see Astr. Nachr., 1833, No. 239; and on the identity of the comet of 1743 and the fourth comet of 1819, see No. 237 of the last-mentioned work.

space; but they must be regarded as isolated occurrences, exercising no more general or alterative effects on cosmical relations than the breaking forth or extinction of a volcano within the limited sphere of our Earth.

A third interior comet, having likewise a short period of revolution, was discovered by Faye on the 22nd of November, 1843, at the Observatory at Paris. Its elliptic path, which approaches much more nearly to a circle than that of any other known comet, is included within the orbits of Mars and Saturn. This comet, therefore, which, according to Goldschmidt, passes beyond the orbit of Jupiter, is one of the few whose perihelia are beyond Mars. Its period of revolution is 728 years, and it is not improbable that the form of its present orbit may be owing to its great approximation to Jupiter at the close of the year 1839.

If we consider the comets in their enclosed elliptic orbits as members of our solar system, and with respect to the length of their major axes, the amount of their eccentricity, and their periods of revolution, we shall probably find that the three planetary comets of Encke, Biela, and Faye are most nearly approached in these respects, first, by the comet discovered in 1766 by Messier, and which is regarded by Clausen as identical with the third comet of 1819; and, next, by the fourth comet of the last-mentioned year, discovered by Blaupain, but considered by Clausen as identical with that of the year 1743, and whose orbit appears, like that of Lexell's comet, to have suffered great variations from the proximity and attraction of Jupiter. The two last-named comets would likewise seem to have a period of revolution not exceeding five or six years, and their aphelia are in the vicinity of Jupiter's orbit. Among the comets that have a period of revolution of from seventy to seventy-six years, the first in point of importance with respect to theoretical and physical astronomy is Halley's comet, whose last appearance, in 1835, was much less brilliant than was to be expected from preceding ones; next we would notice Olbers's comet, discovered on the 6th of March, 1815; and, lastly, the comet discovered by Pons in the year 1812, and whose elliptic orbit has been determined by Encke. The two latter comets were invisible to the naked eye. We now know with certainty of nine returns of Halley's large comet, it having recently been proved by Laugier's calculations,[16] that in

[16]Laugier, in the Comptes Rendus des Séances de l'Academie,

the Chinese table of comets, first made known to us by Edward Biot, the comet of 1378 is identical with Halley's; its periods of revolution have varied in the interval between 1378 and 1835 from 7491 to 7758 years, the mean being 761. A host of other comets may be contrasted with the cosmical bodies of which we have spoken, requiring several thousand years to perform their orbits, which it is difficult to determine with any degree of certainty. The beautiful comet of 1811 requires, according to Argelander, a period of 3065 years for its revolution, and the colossal one of 1680 as much as 8800 years, according to Encke's calculation. These bodies respectively recede, therefore, 21 and 44 times further than Uranus from the Sun, that is to say, 33,600 and 70,400 millions of

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1843, t. xvi., p. 1006.

miles. At this enormous distance the attractive force of the Sun is still manifested; but while the velocity of the comet of 1680 at its perihelion is 212 miles in a second, that is, thirteen times greater than that of the Earth, it scarcely moves ten feet in the second when at its aphelion. This velocity is only three times greater than that of water in most sluggish European rivers, and equal only to half that which I have observed in the Cassiquiare, a branch of the Orinoco. It is highly probable that, among the innumerable host of uncalculated or undiscovered comets, there are many whose major axes greatly exceed that of the comet of 1680. In order to form some idea by numbers, I do not say of the sphere of attraction, but of the distance in space of a fixed star, or other sun, from the aphelion of the comet of 1680 (the furthest receding cosmical body with which we are acquainted in our solar system), it must be remembered that, according to the most recent determinations of parallaxes, the nearest fixed star is full 250 times further removed from our sun than the comet in its aphelion. The comet's distance is only 44 times that of Uranus, while Centauri is 11,000, and 64Cygni 31,030 times that of Uranus, according to Bessels Jeterminations.

Having considered the greatest distances of comets from the central body, it now remains for us to notice instances of the greatest proximity hitherto measured. Lexell and Burckhardts comet of 1770, so celebrated on account of the disturbances it experienced from Jupiter, has approached the Earthwithin a smaller distance than any other comet. On the 28thof June, 1770, its distance from the Earth was only six timesthat of the Moon. The same comet passed twice, viz., in1769 and 1779, through the system of Jupiters four satelliteswithout producing the slightest notable change in the wellknown orbits of these bodies. The great comet of 1680 approached at its perihelion eight or nine times nearer to thesurface of the. Sun than Lexells comet did to that of ourEarth, being on the 17th of December a sixth part of theSuns diameter, or seven tenths of the distance of the Moonfrom that luminary. Perihelia occurring beyond the orbit ofMars can seldom be observed by the inhabitants of the Earth,owing to the faintness of the light of distant comets; andamong those already calculated, the comet of 1729 is the onlyone which has its perihelion between the orbits of Pallas andJupiter ; it was even observed beyond the latter.

Since scientific knowledge, although frequently blended with vague and superficial views, has been more extensively diffused through wider circles of social life, apprehensions of the possible evils threatened by comets have acquired more weight as their direction has become more definite. The certainty that there are within the known planetary orbits comets which revisit our regions of space at short intervals, that great disturbances have been produced by Jupiter and Saturn in their orbits, by which such as were apparently harmless have been converted into dangerous bodies, the intersection of the Earth's orbit by Biela's comet, the cosmical vapor, which, acting as a resisting and impeding medium, tends to contract all orbits, the individual difference of comets, which would seem to indicate considerable decreasing gradations in the quantity of the mass of the nucleus, are all considerations more than equivalent, both as to number and variety, to the vague fears entertained in early ages of the general conflagration of the world by flaming swords and stars with fiery streaming hair. As the consolatory considerations which may be derived from the calculus of probabilities address themselves to reason and to meditative understanding only, and not to the imagination or to a desponding condition of mind, modern science has been accused, and not entirely without reason, of not attempting to allay apprehensions which it has been the very means of exciting. It is an inherent attribute of the human mind to experience fear, and not hope or joy, at the aspect of that which is unexpected and extraordinary.[17] The strange form of a large comet, its faint nebulous light, and its sudden appearance in the vault of heaven, have in all regions been almost invariably regarded by the people at large as some new and formidable agent inimical to the existing state of things. The sudden occurrence and short duration of the phenomenon lead to the belief of some equally rapid reflection of its agency in terrestrial matters, whose varied nature renders it easy to find events that may be regarded as the fulfillment of the evil foretold by the appearance of these mysterious cosmical bodies. In our own day, however, the public mind has taken another

[17]Fries, Vorlesungen uber die Sternkunde, 1833, s. 262267 (Lectureson the Science of Astronomy). An infelicitously chosen instance of thegood omen of a comet may be found in Seneca, Nat. Quest., vii., 17 and21. The philosopher thus writes of the comet Quem nos Neronisprincipatu letissimo vidimus et qui cometis detraxit infamiam.

and more cheerful, although singular, turn with regard to comets; and in the German vineyards in the beautiful valleys of the Rhine and Moselle, a belief has arisen, ascribing to these once ill-omened bodies a beneficial influence on the ripening of the vine. The evidence yielded by experience, of which there is no lack in these days when comets may so frequently be observed, has not been able to shake the common belief in the meteorological myth of the existence of wandering stars capable of radiating heat.

Chapter 7

Aerolites

From comets I would pass to the consideration of a far more enigmatical class of agglomerated matter - the smallest of all asteroids, to which we apply the name aerolites, or meteoric stones.[1] When they

[1] [Much valuable information may be obtained regarding the origin and composition of aerolites or meteoric stones in Memoirs

reach our atmosphere in a fragmentary condition, if I should seem to dwell on the specific enumeration of these bodies, and of comets, longer than the general nature of this work might warrant, I have not done so undesignedly. The diversity existing in the individual characteristics of comets has already been noticed. The imperfect knowledge we possess of their physical character renders it difficult, in a work like the present, to give the proper degree of circumstantiality to the phenomena, which, although of frequent recurrence, have been observed with such various degrees of accuracy, or to separate the necessary from the accidental. It is only with respect to measurements and computations that the astronomy of comets

on the subject, by Baumbeer and other writers, in the numbers of Poggendorf Annalen, from 1845 to the present time.] – Tr.

has made any marked advancement, and, consequently, a scientific consideration of these bodies must be limited to a specification of the difference in physiognomy and conformation in the nucleus and tail, the instances of great approximation to other cosmical bodies, and of the extremes in the length of their orbits and in their periods of revolution. A faithful delineation of these phenomena, as well as of those which we proceed to consider, can only be given by sketching individual features with the animated circumstantiality of reality. Shooting stars, fireballs, and meteoric stones are, with great probability, regarded as small bodies moving with planetary velocity, and revolving in obedience to the laws of general gravity in conic sections around the Sun. When these masses meet the Earth in their course, and are attracted by it, they enter within the limits of our atmosphere in a luminous condition, and frequently let fall more or less strongly heated stony fragments, covered with a shining black crust. When we enter into a careful investigation of the facts observed at those epochs when showers of shooting stars fell periodically in Cumana in 1799, and in North America during the years 1833 and 1834, we shall find that fireballs can not be considered separately from shooting stars. Both these phenomena are frequently not only simultaneous and blended together, but they likewise are often found to merge into one another, the one phenomenon gradually assuming the character of the other alike with respect to the size of their disks, the emanation of sparks, and the velocities of their motion. Although exploding smoking luminous fireballs are sometimes seen, even in the brightness of tropical daylight,[2] equaling in size the apparent

[2]A friend of mine, much accustomed to exact trigonometrical measurements, was in the year 1788 at Popayan, a city which is 2 26 north latitude, lying at an elevation of 5583 feet above the level of the sea, and at noon, when the sun was shining brightly in a cloudless sky, saw his room lighted up by a fireball. He had his back to the window at the time, and on turning round, perceived that great part of the path traversed by the fireball was still illuminated by the brightest radiance. Different nations have had the most various terms to express these phenomena - the Germans use the word Sternschnuppe, literally star snuff, an expression well suited to the physical views of the vulgar in foretimes, according to which, the lights in the firmament were said to undergoa process of snuffing or cleaning ; and other nations generally adopt aterm expressive of a shot or fall of stars, as the Swedish stjernjfall, theItalian stella cadente, and the English star shoot. In the woody districtof the Orinoco, on the dreary banks of the Cassiquiare, I heard the natives in the Mission of Vasiva use terms still more inelegant than theGerman star snuff. (Relation Historique du Voy. aux Régions Equinoz.,t. ii., p. 513.) These same tribes term the pearly drops of dew whichcover the beautiful leaves of the heliconia star spit. In the Lithuanianmythology, the imagination of the people has embodied its ideas of thenature and signification of falling stars under nobler and more gracefulsymbols. The Parc, Werpeja, weave in heaven for the newbornchild its thread of fate, attaching each separate thread to

diameter of the Moon, innumerable quantities of shooting stars have, on the other hand, been observed to fall informs of such extremely small dimensions that they appeatonly as moving points or phosphorescent lines.[3]

It still remains undetermined whether the many luminous bodies that shoot across the sky may not vary in their na-

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a star. Whendeath approaches the person, the thread is rent, and the star wanes andsinks to the earth. Jacob Grimm, Deutsche Mythologie, 1843, s. 685.

[3]According to the testimony of Professor Denison Olmsted, of YaleCollege, New Haven, Connecticut. (See Poggend., Annalen der Physik,bd. xxx., s. 194.) Kepler, who excluded fireballs and shooting starsfrom the domain of astronomy, because they were, according to hisviews, meteors arising from the exhalations of the earth, and blending with the higher ether, expresses himself, however, generally withmuch caution. He says Stelle cadentes sunt materia viscida inflammata. Earum alique inter cadendum absumuntur, alique vere in terramcadunt, pondere suo tracte. Nec est dissimile vero, quasdam conglobatasesse ex materia feculentd, in ipsam auram ethereum immizta exqueatheris regione, tractu rectilineo, per aérem trajicerc, ceu minutos cometas, occulté causa motus utrorumque.Kepler, Epit. Astron. Copernican, t.i., p. 80.

ture. On my return from the equinoctial zones, I was impressed with an idea that in the torrid regions of the tropics I had more frequently than in our colder latitudes seen shooting stars fall as if from a height of twelve or fifteen thousand feet; that they were of brighter colors, and left a more brilliant line of light in their track; but this impression was no doubt owing to the greater transparency of the tropical atmosphere.[4] The connection of mete-

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[4]Relation Historique, t. i., p. 80, 213, 527. If in falling stars, as in comets, we distinguish between the head or nucleus and the tail, we shall find that the greater transparency of the atmosphere in tropical climates is evinced in the greater length and brilliancy of the tail which may be observed in those latitudes. The phenomenon is therefore not necessarily more frequent there, because it is oftener seen and continues longer visible. The influence exercised on shooting stars by the character of the atmosphere is shown occasionally even in our temperate zone, and at very small distances apart. Wartmann relates that on the occasion of a November phenomenon at two places lying very near each other, Geneva and Aux Planchettes, the number of the meteors counted were as 1 to 7. (Wartmann, Mém.

sur les Etoiles filantes, p17.) The tail of a shooting star (or its train), on the subject of which Brandes has made so many exact and delicate observations, is in no way to be ascribed to the continuance of the impression produced by light on the retina. It sometimes continues visible a whole minute, and in some rare instances longer than the light of the nucleus of the shooting star; in which case the luminous track remains motionless. (Gilb., Ann., bd. xiv., 8.251.) This circumstance further indicates the analogy between large shooting stars and fireballs. Admiral Krusenstern saw, in his voyage round the world, the train of a fireball shine for an hour after the luminous body itself had disappeared, and scarcely move throughout the whole time. (Reise, th. i., 8. 58.) Sir Alexander Burnes gives a charming description of the transparency of the clear atmosphere of Bokhara, which was once so favorable to the pursuit of astronomical observations. Bokhara is situated in 39 43 north latitude, and at an elevation of 1280 feet above the level of the sea. There is a constant serenity in its atmosphere, and an admirable clearness in the sky. At night, the stars have uncommon luster, and the Milky Way shines gloriously in the firmament. There is also a never-ceasing display of the most brilliant meteors, which dart like rockets in the sky; ten or twelve of them are sometimes seen in an hour, assuming every color - fiery red, blue, pale, and faint. It is a noble country for astronomical science, and great must have been the advantage enjoyed by the famed observatory of Samarkand. (Burnes, Travels into Bokhara, vol. ii. (1834), p. 158.) A mere traveler must not be reproached for calling ten or twelve shooting stars in an hour many, since it is only recently that we have learned, from careful observations on this subject in Europe, that eight is the mean number which may be seen in oric stones with the grander phenomenon of fireballs, the former being known to be projected from the latter with such force as to penetrate from ten to fifteen feet into the earth, has been proved, among many other instances, in the falls of aérolites at Barbotan, in the Department des Landes (24th July, 1790), at Siena (16th June, 1794), at Weston, in Connecticut, U.S. (14th December, 1807), and at Juvenas, in the Department of Ardéche (15th June, 1821). Meteoric stones are in some instances thrown from dark clouds suddenly formed in a clear sky, and fall with a noise resembling thunder. Whole districts have thus occasionally been covered with thousands of fragmentary masses, of uniform character

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an hour in the field of vision of one individual (Quetelet, Corresp. Mathém., Novem., 1837, p. 447); this number is, however, limited to five or six by that aitigamt observer, Olbers. (Schum., Jahrb., 1838, s. 325.)

but unequal magnitudes, that have been hurled from one of these moving clouds. In less frequent cases, as in that which occurred on the 16th of September, 1843, at Kleinwenden, near Miihlhausen, a large aérolite fell with a thundering crash while the sky was clear and cloudless. The intimate affinity between fireballs and shooting stars is further proved by the fact that fireballs, from which meteoric stones have been thrown, have occasionally been found, as at Angers, on the 9th of June, 1822, having a diameter scarcely equal to that of the small fireworks called Roman candles.

The formative power, and the nature of the physical and chemical processes involved in these phenomena, are questions all equally shrouded in mystery, and we are as yet ignorant whether the particles composing the dense mass of meteoric stones are originally, as in comets, separated from one another in the form of vapor, and only condensed within the fiery ball when they become luminous to our sight, or whether, in the case of smaller shooting stars, any compact substance actually falls, or, finally, whether a meteor is composed only of a smoke-like dust, containing iron and nickel; while we are wholly ignorant of what takes place within the dark cloud from which a noise like thunder is often heard for many minutes before the stones fall.[5]

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[5]On meteoric dust, see Arago, in the Annuaire for 1832, p. 254. I have very recently endeavored to show, in another work (Aste Centrale, t.i., p. 408), how the Scythian saga of the sacred gold, which fell burning from heaven, and remained in the possession of the Golden Horde of the Paralatw (Herod., iv., 57), probably originated in the vague recollection of the fall of an aérolite. The ancients had also some strange fictions (Dio Cassius, lxxv., 1259) of silver which had fallen from heaven, and with which it had been attempted, under the Emperor Severus, to cover bronze coins; metallic iron was, however, known to exist in meteoric stones. (Plin., ii., 56.) The frequently recurring expression apidibus pluit must not always be understood to refer to falls of aérolites. In Liv., xxv.,7, it probably refers to pumice (rapilli) ejected from the volcano, Mount Albanus (Monte Cavo), which was not wholly extinguished at the time. (See Heyne, Opuscula Aeccd., t. iii., p 261; and my Relation. Hist., t.i., p.394.) The contest of Hercules with the Ligyans, on the road from the Caucasus to the Hesperides, belongs to a different sphere of ideas, being an attempt to explain mythically the origin of the round quartz blocks in the Ligyan field of stones at the mouth of the Rhone, which Aristotle supposes to have been ejected from a fissure during an earthquake, and Posidonius to have been caused by the force of the waves of an inland piece of water. In the fragments that we still possess of the play of Aschylus, the Prometheus Delivered, everything proceeds, however, in part of the narration, as in a fall of aérolites, for Jupiter draws together a cloud, and causes the district around to be covered by a shower of round stones. Posidonius even ventured to deride the geognostic myth of the blocks and stones. The Lygian

We can ascertain by measurement the enormous, wonderful, and wholly planetary velocity of shooting stars, fireballs, and meteoric stones, and we can gain a knowledge of what is the general and uniform character of the phenomenon, but not of the genetically cosmical process and the results of the metamorphoses. If meteoric stones while revolving in space are already consolidated into dense masses,[6]

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field of stones was, however, very naturally and well described by the ancients. The district is now known as La Craw. (See Guerin, Mesures Barométriques dans les Alpes, et Météorologie Avignon, 1829, chap. xii., p. 115.)

[6]The specific weight of aerolites varies from 19 (Alais) to 43 (Tabor). Their general density may be set down as 3, water being 1. As to what has been said in the text of the actual diameters of fireballs, we must remark, that the numbers have been taken from the few measurements that can be relied upon as correct. These give for the fireball of Weston, Connecticut (14th December, 1807), only 500; for that observed by Le Roi (10th July, 1771) about 1000, and for that estimated by Sir Charles Blagden (18th January, 1783) 2600 feet in diameter. Brandes (Unterhaltungen, bd. i., 8. 42) ascribes a diameter varying from 80 to 120 feet to shooting stars, and a lumi-

nous train extending from 12 to 16 miles. There are, however, ample optical causes for supposing that the apparent diameter of fireballs and shooting stars has been very much overrated. The volume of the largest fireball yet observed cannot be compared with that of Ceres, estimating this planet to have a diameter of only 72 English miles. (See the generally so exact and admirable treatise, On the Connection of the Physical Sciences, 1835, p. 411.) With the view of elucidating what has been stated in the text regarding the large aerolite that fell into the bed of the River Narni, but has not again been found, I will give the passage made known by Pertz, from the Chronicon Benedicti, Monacht Sancti Andree in Monte Soracte, a MS. belonging to the tenth century, and preserved in the Chigi Library at Rome. The barbarous Latin of that age has been left unchanged. Anno 921, temporibus domini Johannis Decimi pape, in anno pontificatus illius 7 visa sunt signa. Nam juxta urbem Romam lapides plurimi de calo cadere visi sunt. In civitate que vocatur Narnia tam dirt ac tetri, ut nihil aliud credatur, quam de infernalibus locis deducti essent. Nam ita ex illis lapidibus unus omnium maximus est, ut drcidensin flumen Narnus, ad mensuram unius cubiti super aquas fluminis usque hodie videretur. Nam et ignite facule de celo plurime omnibus in hac civitate Romani populi vise sunt, ita ut pene terra contingeret. Alia cadentes, c. (Pertz, Monum. Germ. Hist. Scriptores, t. iii., p. 715.) On the aerolites of gos Potamos, which fell, according to the Parian Chronicle, in the 78 1 Olympiad, see Béckh, Corp. Inscr. Graec., t. ii., p. 302, 320, 340; also Aristot., Meteor., i., 7 (Idelers Comm., t. 1., p. 404-407); Stob., Hcl. Phys., 1, 25, p. 508 (Heeren); Plut., Lys., c. 12; Diog. Laert., ii., 10; and see, also, subsequent notes in this work. According to a Mongolian less dense, however, than the mean density of the earth, they must be very small nuclei, which, surrounded by inflammable vapor or gas, form the innermost part of fireballs, from the height and apparent diameter of which we may, in the case of the largest, estimate that the actual diameter varies from 500 to about 2800 feet. The largest meteoric masses as yet known are those of Otumpa, in Chaco, and of Bahia, in Brazil, described by Rubi de Celis as being from 7 to 74 feet in length. The meteoric stone of Aagos Potamos, celebrated in antiquity, and even mentioned in the Chronicle of the Parian Marbles, which fell about the year in which Socrates was born, has been described as of the size of two

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tradition, a black fragment of a rock, forty feet in height, fell from heaven on a plain near the source of the Great Yellow River in Western China. (Abel Rémusat, in Lamétherie, Jour. de Phys., 1819, Mai, p. 264.)

millstones, and equal in weight to a full wagon load. Notwithstanding the failure that has attended the efforts of the African traveler, Brown, I do not wholly relinquish the hope that, even after the lapse of 2312 years, this Thracian meteoric mass, which it would be so difficult to destroy, may be found, since the region in which it fell is now become so easy of access to European travelers. The huge aerolite which in the beginning of the tenth century fell into the river at Narni, projected between three and four feet above the surface of the water, as we learn from a document lately discovered by Pertz. It must be remarked that these meteoric bodies, whether in ancient or modern times, can only be regarded as the principal fragments of masses that have been broken up by the explosion either of a fireball or a dark cloud.

Figure 7.1: Fragment of El Chaco meteorite. Licensed under CC-BY-SA 4.0. Author: Howardites Meteorites

On considering the enormous velocity with which, as hasbeen mathematically proved, meteoric stones reach the earthfrom the extremest confines of the atmosphere, and the lengthened course traversed by fireballs through the denser strataof the air, if seems more than improbable that these metalliferous stony masses, containing perfectlyformed erystals of olivine, labradorite, and pyroxene, should in so short a period oftime have been converted from a vaporous condition to a solidnucleus. Moreover, that which falls from meteoric masses,even where the internal composition is chemically different,exhibits almost always the peculiar character of a fragment,being of a prismatic or truncated pyramidal form, with broad,somewhat curved faces, and rounded angles. But whencecomes this form, which was first recognized by Schreiber ascharacteristic of the severed part of a rotating planetary body Here, as in the sphere of organic life, all that appertains tothe history of development remains hidden in obscurity. Meteoric masses become luminous and kindle at heights which must be regarded as almost devoid of air, or occupied by atatmosphere that does not even contain y5′;;5th part of oxygen. The recent investigations of Biot on the important phenomenon of twilight[7]

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[7]Biot, Traité d Astronomie Physique (3éme éd.), 1841, t.i., p. 149177, 238, 312. My lamented friend Poisson endeavored, in a singularmanner, to solve the difficulty attending an assumption of the spontaneous ignition of meteoric stones at an elevation where the density ofthe atmosphere is almost null. These are his words It is difficult toattribute, as is usually done, the incandescence of atrolites to frictionagainst the molecules of the atmosphere at an elevation above the earthwhere the density of the air is almost null. May ve not suppose thatthe electric fluid, in a neutral condition, forms a kind of atmosphere, extending far beyond the mass of our atmosphere, yet subject to terrestrial attraction, although physically im-

have considerably lowered the lineswhich had, perhaps with some degree of temerity, been usually termed the boundaries of the atmosphere; but processes oflight may be evolved independently of the presence of oxygen,and Poisson conjectured that aérolites were ignited far beyondthe range of our atmosphere. Numerical calculation and geometrical measurement are the only means by which, as in thecase of the larger bodies of our solar system, we are enabled toimpart a firm and safe basis to our investigations of meteoricstones. Although Halley pronounced the great fireball of 1686,whose motion was opposite to

ponderable, and consequently following our globe in its motion According to this hypothesis, thebodies of which we have been speaking would, on entering this imponderable atmosphere, decompose the neutral fluid by their unequalaction on the two electricities, and they would thus be heated, and ina state of incandescence, by becoming electrified. (Poisson, Rech. surla Probabilité des Jugements, 1837, p. 6.)

that of the earth in its orbit,[8] tobe a cosmical body, Chladni, in 1794, first recognized, withready acuteness of mind, the connection between fireballs andthe stones projected from the atmosphere, and the motions of theformer bodies in space.[9] A brilliant confirmation of the cosmical origin of these phenomena has been afforded by DenisonOlmsted, at New Haven, Connecticut, who has shown, on theconcurrent authority of all eyewitnesses, that during the celebrated fall of shooting stars on the night between the 12th and 13th of

[8]Philos. Transact., vol. xxix., p. 161163. .

[9]The first edition of Chladnis important treatise, Ueber den Ursprung der von Pallas gefundenen und anderen Eisenmassen (On theOrigin of the masses of Iron found by Pallas, and other similar masses),appeared two months prior to the shower of stones at Siena, and twyears before Lichtenberg stated, in the Gottingen Taschenbuch, thastones reach our atmosphere from the remoter regions of space.Comp., also, Olberss letter to Benzenberg, 18th Nov., 1837, in Benzenbergs T'reatise on Shooting Stars, p. 186

November, 1833, the fireballs and shooting starsall emerged from one and the same quarter of the heavens,namely, in the vicinity of the star y in the constellation Leo,and did not deviate from this point, although the star changedits apparent height and azimuth during the time of the observation. Such an independence of the Earths rotation showsthat the luminous body must have reached our atmosphere fromwithout. According to Enckes computation[10] of the whole number of

[10]Encke, in Poggend., Annalen, bd. xxxiii. (1834), s. 213. Arago,in the Annuaire for 1836, p. 291. Two letters which I wrote to Benzenberg, May 19 and October 22, 1837, on the conjectural precessionof the nodes in the orbit of periodical falls of shooting stars. (Benzenbergs Sternsch., s. 207 and 209.) Olbers subsequently adopted thisopinionof the gradual retardation of the November phenomenon(Astron. Nachr., 1838, No. 372, 8. 180.) If I may venture to combinetwo of the falls of shooting stars mentioned by the Arabian writerswith the epochs found by Boguslawski for the fourteenth century, Iobtain the following more or less accordant elements of the movementsof the nodes:

In Oct., 902, on the night in which King Ibrahim ben Ahmed died,there fell a heavy shower of shooting stars, like a fiery rain; andthis year was, therefore, called the year of stars. (Conde, Hist. de laDomin. de los Arabes, p. 346.)

On the 19th of Oct., 1202, the stars were in motion all night. Theytell like locusts. (Comptes Rendus, 1837, t. i., p.294; and Freehn, inthe Bull. de 7 Académie de St. Pétersbourg, t. iii., p. 308.)

On the 2st Oct., O.S., 1366, die sequente post festum XI. millia Virginum ab hora matutina usque ad horam primam vise sunt quasi stellade calo cadere continuo, et in tanta multitudine, quod nemo narrare sufjicit. This remarkable notice, of which we shall speak more fully inthe subsequent part of this work, was found by the younger Von Boguslawski, in Benesse (de ee de Weitmil or Weithmiil, Chrontcon Ecclesiae Pragensis, p. 389. This chronicle may also be found inthe second part of Scriptores rerum Bohemicarum, by Pelzel and Dobrowsky, 1784. (Schum., Astr. Nachr., Dec., 1839.)

On the night between the 9th and 10th of November, 1787, many falling stars were observed at Manheim, Southern Germany, by Hemmer(Kamtz, Meteor., th. iii., s. 237.)

After midnight, on the 12th of November, 1799, occurred the extraordinary fall of stars at Cumana, which Bonpland and myself have described, and which was observed over a great part of the earth. (RelatHist., t. i., p. 519527.)

Between the 12th and 13th of November, 1822, shooting stars, inter.mingled with fireballs, were seen in large numbers by Kloden, atPotsdam. (Gilberts Anz., bd. xxii., s. 291.)

On the 13th of November, 1831, at 4 oclock in the morning, a greatshower of falling stars was seen by Captain Bérard, on the Spanish-observations made in the United States of NorthAmerica, between the thirtyfifth and the fortysecond degreesof latitude, it would appear that all these meteors came fromthe same point of space in the direction in which the Earthwas moving at the time. On the recurrence of falls of shooting stars in North America, in the month of November of theyears 1834. and 1837, and in the analogous falls observed atBremen

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coast, near Carthagena del Levante. (Annuaire, 1836, p. 297.)

In the night between the 12th and 13th of November, 1833, occurredthe phenomenon so admirably described by Professor Olmsted, inNorth America.

Tn the night of the 1314th of November, 1834, a similar fall of shooting stars was seen in North America, although the numbers were notquite so considerable. (Poggend., Annalen, bd. xxxiv., s. 129.)

On the 13th of November, 1835, a barn was set on fire by the fall ofa sporadic fireball, at Belley, in the Department de lAin. (Annuaire,1836, p. 296.)

In the year 1838, the stream showed itself most decidedly on thenight of the 1314th of November. (Astron. Nachr., 1838, No. 372.)

in 1838, a like general parallelism of the orbits, andthe same direction of the meteors from the constellation Leo,were again noticed. It has been supposed that a greaterparallelism was observable in the direction of periodic falls ofshooting stars than in those of sporadic occurrence ; and it hasfurther been remarked, that in the periodicallyrecurring fallsin the month of August, as, for instance, in the year 1839, whemeteors came principally from one point between Perseus andTaurus, toward the latter of which constellations the Earthwas then moving. This peculiarity of the phenomenon, manifested in the retrograde direction of the orbits in Novemberand August, should be thoroughly investigated by accurateobservations, in order that it may either be fully confirmed or refuted.

The heights of shooting stars, that is

to say, the heights of the points at which they begin and cease to be visible, vary exceedingly, fluctuating between 16 and 140 miles. This important result, and the enormous velocity of these problematical asteroids, were first ascertained by Benzenberg and Brandes, by simultaneous observations and determinations of parallax at the extremities of a base line of 49,020 feet in length.[11] The relative velocity of motion is from 18 to 36 miles in a second, and consequently equal to planetary velocity. This planetary velocity,[12] as well

[11] I am well aware that, among the 62 shooting stars simultaneously observed in Silesia, in 1823, at the suggestion of Professor Brandes some appeared to have an elevation of 183 to 240, or even 400 miles. (Brandes, Unterhaltungen für Freunde der Astronomie und Physik, hefti., s. 48. Instructive Narratives for the Lovers of Astronomy and Physics.) But Olbers considered that all determinations for elevations beyond 120 miles must be doubtful, owing to the smallness of the parallax.

[12] The planetary velocity of translation, the movement in the orbit, is in Mercury 264, in Venus 193, and in the Earth 164 miles in a

as the direction of the orbits of fireballs and shooting stars, which has frequently been observed to be opposite to that of the Earth, may be considered as conclusive arguments against the hypothesis that aérolites derive their origin from the so-called active lunar volcanoes. Numerical views regarding a greater or lesser volcanic force on a small cosmical body, not surrounded by any atmosphere, must, from their nature, be wholly arbitrary. We may imagine the reaction of the interior of a planet on its crust ten or even a hundred times greater than that of our present terrestrial volcanoes; the direction of masses projected from a satellite revolving from west to east might appear retrogressive, owing to the Earth in its orbit subsequently reaching that point of space at which these bod-

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second.

ies fall. If we examine the whole sphere of relations which I have touched upon in this work, in order to escape the charge of having made unproved assertions, we shall find that the hypothesis of the selenic origin of meteoric stones[13] depends upon

[13]Chladni states that an Italian physicist, Paolo Maria Terzago, onthe occasion of the fall of an aérolite at Milan in 1660, by which a Franciscan monk was killed, was the first who surmised that aérolites wereof selenic origin. He says, in a memoir entitled Museum Septalianum,Manfredi Septale, Patricit Mediolanensis, industrioso labore constructumTortona, 1664, p. 44), Labant philosophorum mentes sub horum lapidumponderibus; ni dicire velimus, lunam terram alteram, sine mundum esse,ex cujus montibus divisa frustra in inferiorem nostrum hunc orbem delabantur. Without any previous knowledge of this conjecture, Olberswas led, in the year 1795 (after the celebrated fall at Siena on the 16thof June, 1794), into an investigation of the amount of the initial tangential force that would be requisite to bring to the Earth masses projected from the Moon. This ballistic problem occupied, during ten ortwelve years, the attention of the geometricians Laplace, Biot, Brandes,and Poisson. The opinion which was then so prevalent, but which hassince been abandoned, of the existence of active volcanoes in the Moon,where air and water are absent, led to a confusion in the minds of thegenerality of persons between mathematical possibilities and physical-

probabilities. Olbers, Brandes, and Chladni thought that the velocityof 16 to 32 miles, with which fireballs and shooting stars entered ouratmosphere, furnished a refutation to the view of their selenic origin.According to Olbers, it would require to reach the Earth, setting asidethe resistance of the air, an initial velocity of 8292 feet in the second 5according to Laplace, 7862 ; to Biot, 8282; and to Poisson, 7595. Laplace states that this velocity is only five or six times as great as that ofacannon ball; but Olbers has shown that, with such an initial veloc.ity as 7500 or 8000 feet in a second, meteoric stones would arrive at thesurface of our earth with a velocity of only 35,000 feet (or 153 Germangeographical mile). But the measured velocity of meteoric stones averages five such miles, or upward of 114,000 feet to a second; and,consequently, the original velocity of projection from the Moon mustbe almost 110,000 feet, and therefore fourteeu times greater than Laplace asserted. (Olbers, in Schum., Jahrd., 1837, p. 5258; and in Gehler, Neues Physik. Worterbuche, bd. vi., abth. 3, s. 21292136.) Ifwe could assume volcanic forces to be still active on the Moons surface,the absence of atmospheric resistance would certainly give to theirprojectile force an advantage over that of our terrestrial volcanoes; buteven in respect to the measure of the latter force (the projectile forceof our own volcanoes), we have no observations on which any reliancecan be placed, and it has probably been exceedingly overrated. Dr.Peters, who accurately observed and measured the phenomena .presented by tna, found that the greatest velocity of any of the stones projected from the crater was only 1250 feet toa second. Observationson the Peak of Teneriffe, in 1798, gave 3000 feet. Although Laplace,at the end of his work (Expos. du Syst. du Monde, ed. de 1824, p. 399),cautiously observes, regarding aérolites, that in all probability theycome from the depths of space, yet we see from another passage(chap. vi., p. 233) that, being probably unacquainted with the extraordinary planetary yelocity of meteoric stones, he inclines to the hypothesis of their lunar origin, always, however, assuming that the stonesprojected from the Moon become satellites of our Earth, describingaround it more or less eccentric orbits, and thus not reaching its atmosphere until several or even many revolutions have been accomplished.As an Italian at Tortona had the fancy that aérolites came from theMoon, so some of the Greek philosophers thought they came from theSun. This was the opinion of Diogenes Laertius (ii., 9) regarding theorigin of the mass that fell at A.gos Potamos (see note, p. 116). Pliny,whose labors in recording the opinions and statements of precedingwriters are astonishing, repeats the theory, and derides it the morefreely, because he, with earlier writers (Diog. Laert., 3 and 5, p. 99,Hibner), accuses Anaxagoras of having predicted tlie fall of aérolitesfrom the Sun Celebrant Greci Anaxagoram Clazomenium Olympiadis septuagesime octave secundo anno predixisse celestiam litterarum scientia, quibus diebus saxum casurum esse e sole, idque factuminterdiu in Thracie parte ad Agos flumen. Quod si quis predictumcredat, simul fateatur necesse est, majoris miraculi divinitatem Anaxagore fuisse, solvique rerum nature intellectum, et confundi omnia, siaut ipse Sol lapis esse aut unquam lapidem in eo fuisse credatur; decidere tamen crebro non erit dubium. The fall of a moderatesizedstone, which is preserved in the Gymnasium at Abydos, is also reperted to have been foretold by Anaxagoras. The fall of aérotites in brightsunshine, and when the Moons disk was invisible, probably led to theidea of sunstones. Moreover, according to one of the physical dogmasof

Anaxagoras, which brought on him the persecution of the theologians(even as they have attacked the geologists of our own times), the Sunwas regarded as (a molten fiery mass (uédpoc dtdtupoc). In accordance with these views of Anaxagoras, we find Euripides, in Phagton,terming the Sun a golden mass; that is to say, a firecolored, brightlyshining matter, but not leading to the inference that aérolites aregolden sunstones. (See note to page 115.) Compare Valckenaer,Diatribe in Eurip. perd. Dram. Reliquias, 1767, p. 30. Diog. Laert.,ii, 40. Hence, among the Greek philosophers, we find four hypothesesregarding the origin of falling stars a telluric origin from ascendingexhalations; masses of stone raised by hurricane (see Aristot., Meteor.,lib. i., cap. iv., 213, and cap. vii., 9); a solar origin; and, lastly, an origin in the regions of space, as heavenly bodies which had long remained invisible. Respecting this last opinion, which is that of Diogenes of Apollonia, and entirely accords with that of the present day,see pages 124 and 125. Itis worthy of remark, that in Syria, as I havebeen assured by a learned Orientalist, now resident at Smyrna, Andreade Nericat, who instructed me in Persian, there is a popular belief thataérolites chiefly fall on clear moonlight nights. The ancients, on thecontrary, especially looked for their fall during lunar eclipses. (SeePliny, xxxvil., 10, p. 164. Solinus, c. 37. Salm., Ezere., p. 531; andthe passages collected by Ukert, in his Geogr. der Griechen und Rémer,th. ii., 1, 8. 331, note 14.) On the improbability that meteoric massesare formed from metaldissolving gases, which, according to Fusinieri,may exist in the highest strata of our atmosphere, and, previously diffused through an almost boundless space, may suddenly assume a solidcondition, and on the penetration and misceability of gases, see myRelat. Hist., t. i., p. 525.

a number of conditions. whose accidental coincidence could alone convert a possi-bleinto an actual fact. The view of the original existence of small planetary masses in space is simpler, and, at the sametime, more analogous with those entertained concerning theformation of other portions of the solar system.

It is very probable that a large number of these cosmic bodies traverse space undestroyed by the vicinity of our atmosphere, and revolve around the Sun without experiencing any alteration but a slight increase in the eccentricity of their orbits, occasioned by the attraction of the Earth's mass. We may, consequently, suppose the possibility of these bodies remaining invisible to us during many years and frequent revolutions. The supposed phenomenon of ascending shooting stars and fireballs, which Chladni has unsuccessfully endeavored to explain on the hypothesis of the reflection of strongly compressed air, appears at first sight as the consequence of some unknown tangential force propelling bodies from the earth; but Bessel has shown by theoretical deductions, confirmed by Feldt's carefully conducted calculations, that, owing to the absence of any proofs of the simultaneous occurrence of the observed disappearances, the assumption of an ascent of shooting stars was rendered wholly improbable, and inadmissible as a result of observation.[14] The opinion advanced by Olbers that the explosion of shooting stars and ignited fireballs not moving in straight lines may impel mete-

[14]Bessel, in Schum., Asir. Nachr., 1839, No 380 und 381, s. 222 und 346. At the conclusion of the Memoir there is a comparison of the Sun's longitudes with the epochs of the November phenomenon, from the period of the first observations in Cumana in 1798

ors upward in the manner of rockets, and influence the direction of their orbits, must be made the subject of future researches.

Shooting stars fall either separately and in inconsiderablenumbers, that is, sporadically, or in swarms of many thousands. Ihe latter, which are compared by Arabian authorsto swarms of locusts, are periodic in their occurrence, andmove in streams, generally in a parallel direction. Amongperiodic falls, the most celebrated are that known as the November phenomenon, occurring from about the 12th to the14th of November, and that of the festival of St. Lawrence(the 10th of August), whose fiery tears were noticed informer times in a church calendar of England, no less thanin old traditionary legends, as'a meteorological event of constant recurrence.[15]

[15]Dr. Thomas Forster (Lhe Pocket Encyclopedia of Natural Phe-

Notwithstanding the great quantity of- shooting stars and fireballs of the most various dimensions,which, according to Kloden, were seen to fall at Potsdam on the night between the 12th and 13th of November, 1822,and on the same night of the year in 1832 throughout thewhole of Europe, from Portsmouth to Orenburg on the UralRiver, and even in the southern hemisphere, as in the Isle ofFrance, no attention was directed to the periodicity of thephenomenon, and no idea seems to have been entertained ofthe connection

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nomena, 1827, p. 17) states that a manuscript is preserved in the library of Christ's College, Cambridge, written in the tenth century by amonk, and entitled Ephemerides Rerum Naturalium, in which the natural phenomena for each day of the year are inscribed, as, for instance,the first flowering of plants, the arrival of birds, c.; the 10th of August is distinguished by the word meteorodes. It was this indication, and the tradition of the fiery tears of St. Lawrence, that chiefly-induced Dr. Forster to undertake his extremely zealous investigationof the August phenomena. (Quetelet, Correspond. Mathém., Série II1.,t. 1.,1837, p. 433.) ;

existing between the fall of shooting stars andthe recurrence of certain days, until the prodigious swarm ofshooting stars which occurred in North America between the12th and 13th of November, 1833, and was observed byOlmsted and Palmer. The stars fell, on this occasion, likeflakes of snow, and it was calculated that at least 240,000had fallen during a period of nine hours. Palmer, of NewHaven, Connecticut, was led, in consequence of this splendidphenomenon, to the recollection of the fall of meteoric stonesin 1799, first described by Ellicot and myself,[16] and which,

[16]Humb., Rel. Hist., t. i., p. 519527. Ellicot, in the Transactionsof the American Society, 1804, vol. vi., p.29. Arago makes the following observations in reference to the November phenomena We thusbecome more and more confirmed in the belief that there exists a zonecomposed of millions of small bodies, whose orbits cut the plane of the ecliptic at about the point which our Earth annually occupies betweenthe 11th and 13th of November. It is a new planetary world beginning to be revealed to us. (Annuaire, 1836, p. 296.)

by a comparison of the facts I had adduced, showed that thaphenomenon had been simultaneously seen in the New Continent, from the equator to New Herrnhut in Greenland (6414 north latitude), and between 46. and 82 longitude.The identity of the epochs was recognized with astonishment.The stream, which had been seen from Jamaica to Boston(40 21 north latitude) to traverse the whole vault of heavenon the 12th and 13th of November, 1833, was again observedin the United States in 1834, on the night between the 13thand 14th of November, although on this latter occasion itshowed itself with somewhat less intensity. In Europe thep-

[No such manuscript is at present known to exist in the library of that college.For this information I am indebted to the inquiries of Mr. Cory, of Pembroke Colen a learned editor of Hieroglyphics of Horapollo Nilovs, Greek and English,1840.] – Tr.

eriodicity of the phenomenon has since been manifested withgreat regularity.

Another and a like regularly recurring phenomenon is that noticed in the month of August, the meteoric stream of St. Lawrence, appearing between the 9th and 14th of August. Muschenbroek,[17] as

[17]On the 25th of April, 1095, innumerable eyes in France saw stars falling from heaven as thickly as hail (wt grando, nisi lucerent, pro densitate putaretur; Baldr., p. 88), and this occurrence was regarded by the Council of Clermont as indicative of the great movement in Christendom. (Wilken, Gesch. der Kreuzzige, bd. i.,8. 75.) On the 25th of April, 1800, a great fall of stars was observed in Virginia and Massachusetts; it was (a fire of rockets that lasted two hours. Arago was the first to call attention to this trainée dasteroides, as a recurring phenomenon. (Annuaire, 1836, p. 297.) The falls of aérolites in the beginning of the month of December are also deserving of notice. In reference to their periodic recurrence as a meteoric stream, we may mention the early observation of Brandes on the night of the 6th and 7th of December, 1798 (when he counted 2000 falling stars), and very probably the enormous fall of aérolites that occurred at the Riv Assu, near the village of Macao, in the Brazils, on the 11th of December, 1836. (Brandes, Unterhalt. fur Freunde der Physik, 1825, heft i., s. 65, and Comptes Rendus, t. v.,p.211.) Capocci, in the interval between 1809 and 1839, a space of thirty years, has discov-

early as in the middle of the last century, drew attention to the frequency of meteors in the month of August; but their certain periodic return about the time of St. Lawrence's day was first shown by Quetelet, Olbers, and Benzenberg. We

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ered twelve authenticated cases of aérolites occurring between the 27th and 29th of November, besides others on the 13th of November, the 10th of August, and the 17th of July. (Comptes Rendus, t. xi., p. 357.) It is singular that in the portion of the Earth's path corresponding with the months of January and February, and probably also with March, no periodic streams of falling stars or aérolites have as yet been noticed; although, when in the South Sea in the year 1803, I observed on the 15th of March a remarkably large number of falling stars, and they were seen to fall as in a swarm in the city of Quito, shortly before the terrible earthquake of Riobamba on the 4th of February, 1797. From the phenomena hitherto observed, the following epochs seem especially worthy of remark: 22nd to the 25th of April, 17th of July (17th to the 26th of July). (Quet., Corr., 1837, p. 435.) 10th of August, 12th to the 14th of November, 27th to the 29th of November, 6th to the 12th of December. When we consider that the regions of space must be occupied by myriads of comets, we are led by analogy, notwithstanding the differences existing between isolated comets and rings filled with asteroids, to regard the frequency of these meteoric streams with less astonishment than the first consideration of the phenomenon would be likely to excite. ;

shall, no doubt, in time, discover other periodically appearing streams,[18] probably about the 22nd to the 25th of April, between the 6th and 12th of December, and, to judge by the number of true falls of aérolites enumerated by Capoccei, also between the 27th and 29th of November, or about the 17th of July.

Although the phenomena hitherto observed appear to have been independent of the distance from the pole, the temperature of the air, and other climatic relations,

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[18]Compare Muschenbroek, Introd. ad Phil. Nat., 1762, t. ii., p. 1061; Howard, On the Climate of London, vol. ii., p. 23, observations of the year 1806; seven years, therefore, after the earliest observations of Brandes (Benzenberg, aber Slernschnuppen, s. 240244); the August observations of Thomas Forster, in Quetelet, op. cit., p. 438453; those of Adolph Erman, Boguslawski, and Kreil, in Schum., Jakrb., 1838, s. 317330. Regarding the point of origin in Perseus, on the 10th of August, 1839, see the accurate measurements of Bessel and Erman (Schum., Astr. Nachr., No. 385 und 428); but on the 10th of August, 1837, the path does not appear to have been retrograde; see Arago, in Comptes Rendus, 1837, t. ti., p. 183.

there is, however, one perhaps accidentally coincident phenomenon which must not be wholly disregarded. The Northern Light, the Aurora Borealis, was unusually brilliant on the occurrence of the splendid fall of meteors of the 12th and 13th November, 1833, described by Olmsted. It was also observed at Bremen in 1838, where the periodic meteoric fall was, however, less remarkable than at Richmond, near London. I have mentioned in another work the singular fact observed by Admiral Wrangel, and frequently confirmed to me by himself,[19] that when he was on

[19]Ferd. v. Wrangle, Reise längs der Nordkiste von Sibirien in den Jahren, 1820-1824, th. ii., s. 259. Regarding the recurrence of the denser swarm of the November stream after an interval of thirty-three years, see Olbers, in Jzhrb., 1837, s. 280. I was informed in Cumanathat shortly before the fearful earthquake of 1766; and consequently thirty-three years (the same interval) before the great fall of stars on the 11th and 12th of November, 1799, a similar fiery manifestation had been observed in the heavens. But it was on the 21st of

the Siberian coast of the Polar Sea, he observed, during an Aurora Borealis, certain portions of the vault of heaven, which were not illuminated, light up and continue luminous whenever a shooting star passed over them.

The different meteoric streams, each of which is composed of myriads of small cosmical bodies, probably intersect our Earth's orbit in the same manner as Biela's comet. According to this hypothesis, we may represent to ourselves these asteroid meteors as composing a closed ring or zone, within which they all pursue one common orbit. The smaller planets be-

October, 1766, and not in the beginning of November, that the earthquake occurred. Possibly some traveler in Quito may yet be able to ascertain the day on which the volcano of Cayambe, which is situated there, was for the space of an hour enveloped in falling stars, so that the inhabitants endeavored to appease heaven by religious processions. (Relat. Hist., i., chap. iv., p. 307; chap. x., p. 520 and 527.)

tween Mars and Jupiter present us, if we except Pallas, with an analogous relation in their constantly intersecting orbits. As yet, however, we have no certain knowledge as to whether changes in the periods at which the stream becomes visible, or the retardations of the phenomena of which I have already spoken, indicate a regular precession or oscillation of the nodes—that is to say, of the points of intersection of the Earth's orbit and of that of the ring; or whether this ring or zone attains so considerable a degree of breadth from the irregular grouping and distances apart of the small bodies, that it requires several days for the Earth to traverse it. The system of Saturn's satellites shows us likewise a group of immense width, composed of most intimately connected cosmical bodies. In this system, the orbit of the outermost (the seventh) satellite has such a vast diameter, that the Earth, in her revolution round the Sun, requires three days to traverse an extent of space equal to this diameter. If, therefore, in one of these rings, which we regard as the orbit of a periodical stream, the asteroids should be so irregularly distributed as to consist of but few groups sufficiently dense to give rise to these phenomena; we may easily understand why we so seldom witness such glorious spectacles as those exhibited in the November months of 1799 and 1833. The acute mind of Olbers led him almost to predict that the next appearance of the phenomenon of shooting stars and fireballs intermixed, falling like flakes of snow, would not recur until between the 12th and 14th of November, 1867.

The stream of the November asteroids has occasionally only been visible in a small section of the Earth. Thus, for instance, a very splendid meteoric shower was seen in England in the year 1837, while a most attentive and skillful observer at Braunsberg, in Prussia, only saw, on the same night, which was there uninterruptedly clear, a few sporadic shooting stars fall between seven o'clock in the evening and sunrise the next morning. Bessel[20] concluded from this that a dense group of the bodies composing the great ring may have reached that part of the Earth in which England is situated, while the more eastern districts of the Earth might be passing at the time through a part of the meteoric ring pro-

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[20]From a letter to myself, dated Jan. 24th, 1838. The enormous swarm of falling stars in November, 1799, was almost exclusively seen in America, where it was witnessed from New Herrnhut in Greenland to the equator. The swarms of 1831 and 1832 were visible only in Europe, and those of 1833 and 1834 only in the United States of North America.

portionally less densely studded with bodies. If the hypothesis of a regular precession or oscillation of the nodes should acquire greater weight, special interest will be attached to the investigation of older observations. The Chinese annals, in which great falls of shooting stars, as well as the phenomena of comets, are recorded, go back beyond the age of Tyrteus, or the second Messenian war. They give a description of two streams in the month of March, one of which is 687 years anterior to the Christian era. Edward Biot has observed that, among the fifty-two phenomena which he has collected from the Chinese annals, those that were of most frequent recurrence are recorded at periods nearly corresponding with the 20th and 22nd of July, O.S., and might consequently be identical with the stream of St.

Lawrence's day, taking into account that it has advanced since the epochs[21] indicated. If the fall of shooting stars of the 21st of October, 1366, O.S. (a notice of which was found by the younger Von Boguslawski, in Benessius de Horowies Chronicon Ecclesie Pragensis), be identical with our November phenomenon, although the occurrence in the fourteenth century was seen in broad daylight, we find by the precession in 477 years that this system of meteors, or, rather, its common center of gravity, must describe a retrograde orbit round the Sun. It also follows, from the views thus developed, that the nonappearance, during certain years, in any portion

[21] Lettre de M. Edouard Biot A M. Quetelet, sur les anciennes apparitions dEtoiles Filantes en Chine, in the Bull. de P Académie de Bruxelles, 1843, t. x., No. 7, p. 8. On the notice from the Chronicon Ecclesie Pragensis, see the younger Boguslawski,iu Poggend., Annalenbd. xlviii., 8. 612.

of the Earth, of the two streams hitherto observed in November and about the time of St. Lawrence's day, must be ascribed either to an interruption in the meteoric ring, that is to say, to intervals occurring between the asteroid groups, or, according to Poisson, to the action of the larger planets[22] on the form and position of this annulus.

The solid masses which are observed

[22]It appears that an apparently inexhaustible number of bodies, too small to be observed, are moving in the regions of space, either around the Sun or the planets, or perhaps even around their satellites. It is supposed that when these bodies come in contact with our atmosphere, the difference between their velocity and that of our planet is so great, that the friction which they experience from their contact with the air heats them to incandescence, and sometimes causes their explosion. If the group of falling stars form an annulus around the Sun, its velocity of circulation may be very different from that of our Earth; and the displacements it may experience in space, in consequence of the actions of the various planets, may render the phenomenon of its intersecting the planes of the ecliptic possible at some epochs, and altogether impossible at others. Poisson, Recherches sur la Probabilité des Jugoments, p. 306, 307.

by night to fall to theearth from fireballs, and by day, generally when the sky iscleat, from a dark small cloud, are accompanied by muchnoise, and although heated, are not in an actual state of incandescence. They undeniably exhibit a great degree of general identity with respect to their external form, the characterof their crust, and the chemical composition of their principalconstituents. These characteristics of identity have been observed at all the diflerent epochs and in the most various partsaf the earth in which these meteoric stones have been found.This striking and earlyobserved analogy of physiognomy inthe denser meteoric masses is, however, met by many exceptions regarding individual points. What differences, for instance, do we not find between the malleable masses of ironof Hradschina in the district of Agram, those from the shoresof the Sisim in the government of Jeniseisk, rendered so celebrated by Pallas, or those which I brought from Mexico,[23] allof which contain 96 per cent. of iron, from the aérolites ofSiena, in which the iron scarcely amounts to 2 per cent., orthe earthy aérolite of Alais (in the Department du Gard),which broke up in water, or, lastly, from those of Jonzac andJuvenas, which contained no metallic iron, but presented a mixture of oryctogncstically distinct crystalline components These differences have led mineralogists to separate these cosmical masses into two classes, namely, those containing nickelliferous meteoric iron, and those consisting of fine or coarselygranular meteoric dust. The

[23]Humboldt, Essai Politique sur la Nouv. Espagne (2de édit.), t. iii. p. 310.F 2

crust or rind of aérolites ispeeuliarly characteristic of these bodies, being only a few-tenths of a line in thickness, often glossy and pitchlike, andoccasionally veined.[24] There is only one instance on record,as far as I am aware (the aérolite of Chantonnay, in La Vendée), in which the rind was absent, and this meteor, like thatof Juvenas, presented likewise the peculiarity of having poresand vesicular cavities. In all other cases the black crust isdivided from the inner lightgray mass by as sharplydefineda line of separation as is the black leadencolored investmentof the whité granite blocks[25] which I brought from the catacacts of the Orinoco, and

[24]The peculiar tolor of their crust was observed even as early as inthe time of Pliny (ii., 56 and 58) colore adusto. The phrase lateribus pluisse seems also to refer to the burned outer surface of aérolites

[25]Humb., Rel. Hiést., t. ii., chap xx., p. 299302.

which are also associated withmany other cataracts, as, for instance, those of the Nile andof the Congo River. The greatest heat employed in ourporcelain ovens would be insufficient to produce any thingsimilar to the crust of meteoric stones, whose interior remains wholly unchanged. Here and there, facts have beenobserved which would seem to indicate a fusion together ofthe meteoric fragments ; but, in general, the character of theageregate mass, the absence of compression by the fall, andthe inconsiderable degree of heat possessed by these bodieswhen they reach the earth, are all opposed to the hypothesisof the interior being in a state of fusion during their shortpassage from the boundary of the atmosphere to our Earth.The chemical elements of which these meteoric massesconsist, and on which Berzelius has thrown so much light,are the same as those distributed throughout the earth-scrust, and are fifteen in number, namely, iron, nickel, cobalt,manganese, chromium, copper, arsenic, zinc, potash, soda, sulphur, phosphorus, and carbon, constituting altogether nearlyone third of all the known simple bodies. Notwithstandingthis similarity with the primary elements into which inorganicbodies are chemically reducible, the aspect of aérolites, owingto the mode in which their constituent parts are compounded,presents, generally, some features foreign to our telluric rocksand minerals. The pure native iron, which is almost always found incorporated with aérolites, imparts to them a peculiar, but not, consequently, a selentc character; for in otherregions of space, and in other cosmical bodies besides our

Moon,water may be wholly absent, and processes of oxydation ofrare occurrence.

Cosmical gelatinous vesicles, similar to the organic nostoc(masses which have been supposed since the Middle Ages tobe connected with shooting stars), and those pyrites of Sterlitamak, west of the Uralian Mountains, which are said to havecon-stituted the interior of hailstones,[26] must both be classedamong the mythical fables of meteorology. Some few aérolites, as those composed of a finely granular tissue of olivine,auyite, and labradorite blended together[27] (as the meteoric stonefound at

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[26]Gustav Rose, Reise nach dem Ural, bd. ii., 8. 202.

[27]Gustav Rose, in Poggend., Ann., 1825, bd. iv., s. 173192. Rammelsberg, Erstes Suppl. zum chem. Handwérterbuche der Mineralogie,1843, 8. 102. It is, says the clearminded observer Olbers, a remarkable but hitherto unregarded fact, that while shells are found insecondary and tertiary formations, no fossil meteoric stones have as yetbeen discovered. May we conclude from this circumstance that previous to the present and last modification of the earths sur-

Juvenas, in the Department de Ardéche, which resembled dolorite), are the only ones, as Gustav Rose hasremarked, which have a more familiar aspect. These bodiescontain, for instance, crystalline substances, perfectly similarto those of our earths crust ; and in the Siberian mass ofmeteoric iron investigated by Pallas, the olivine only differsfrom cormmon olivine by the absence of nickel, which is replaced by oxyd of tin.[28] As meteoric olivine,

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face no meteoric stones fell on it, although at the present time it appears probable,from the researches of Schreibers, that 700 fall annually (Olbers,in Schum., Jakrb., 1838, 5. 329.) Problematical nickelliferous massesof native iron have been found in Northern Asia (at the goldwashingestablishment at Petropawlowsk, eighty miles southeast of Kusnezk),imbedded thirtyone feet in the ground, and more recently in the Western Carpathians (the mountain chain of Magura, at Szlanicz), both ofwhich are remarkably like meteoric stones. Compare Erman, Archiafir wissenschaftliche Kunde von Russland, bd.i., 8.315, and Haidinger,Bericht uber Szlaniczer Schiurfe i. Ungarn.

[28]Berzelius, Jahresber., bd. xv. 3. 217 und 231. Rammels-

like our basalt,contains from 47 to 49 per cent. of magnesia, constituting,according to Berzelius, almost the half of the earthy components of meteoric stones, we can not be surprised at the greatquantity of silicate of magnesia found in these cosmical bodies.If the aérolite of Juvenas contain separable crystals of augiteand labradorite, the numerical relation of the constituents render it at least probable that the meteoric masses of ChateauRenard may be a compound of diorite, consisting of hornblende and albite, and those of Blansko and Chantonnay com.pounds of hornblende and labradorite. The proofs of the telluric and atmospheric origin of aérolites, which it is attempted to base upon the oryctognostic analogies presented by thesebodies, do not appear to me to possess any great

berg.Handworterb., abth. ii., 3. 2528.

weight.Recalling to mind the remarkable interview between Newton and Conduit at Kensington,[29] I would ask why the elementary substances that compose one group of cosmical bodies,or one planetary system, may not, in a great measure, be identical Why should we not adopt this view, since we mayconjecture that these planetary bodies, like all the larger orsmaller agglomerated masses revolving round the sun, havebeen thrown off from the once far more expanded solar atmosphere, and been formed from vaporous rings describingtheir orbits round the central body We are not, it appearsto me, more justified in applying the term telluric to the nickeland iron, the olivine and pyroxene

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[29]Sir Isaac Newton said he took all the planets to be composed ofthe same matter with the Earth, viz., earth, water, and stone, but variously concocted.Turner, Collections for the History of Granthamtontaining authentic Memoirs of Sir Isaac Newton, p. 172.

(augite), found in meteoriestones, than in indicating the German plants which I foundbeyond the Obi as European species of the flora of NorthernAsia. If the elementary substances composing a group ofcosmical bodies of different magnitudes be identical, whyshould they not likewise, in obeying the laws of mutual attraction, blend together under definite relations of mixture, ,composing the white glittering snow and ice in the polar zonesof the planet Mars, or constituting in the smaller cosmicalmasses mineral bodies inclosing crystals of olivine, augite, andlabradorite Even in the domain of pure conjecture we shouldnot suffer ourselves to be led away by unphilosophical and arbitrary views devoid of the support of inductive reasoning.Remarkable obscurations of the suns disk, during whichthe stars have been seen at midday (as, for instance, in theobseu-ration of 1547, which continued for three days, and occurred about the time of the eventful battle of Mihlberg),can not be ex-plained as arising from volcanic ashes or mists,and were regarded by Kepler as ow-ing either to a materiacometica, or to a black cloud formed by the sooty exhala-tionsof the solar bedy. The shorter obscu-rations of 1090 and203, which continued, the one only three, and the other six hours, were supposed by Chladni and Schnurrer to be occasioned by the passage of mete-oric masses before the suns disk.Since the period that streams of meteoric shooting stars werefirst considered with reference to the direction of their orbitas a closed ring, the epochs of these mysterious ce-lestial phenomena have been observed to present a remarkable connection with the regular recurrence of swarms of shooting starsAdolph Erman has evinced great acuteness of mind in his accurate Investigation of the facts hitherto observed on this subject, and his researches have enabled him to discover the connection of the suns conjunction with the August asteroids onthe 7th of February, and with the November asteroids on the12th of May, the latter period corresponding with the daysof St. Mamert (May 11th), St. Pancras (May 12th), and St.Servatius (May 13th), which, according to popular belief,were accounted cold days.[30]

[30]Adolph Erman, in Poggend., Annalen, 1839, bd. xlviii., s. 582601. Biot had previously thrown doubt regarding the probability of ,the November stream reappearing in the beginning of May (ComptesRendus, 1836, t. ii., p. 670). Madler has examined the mean depression of temperatare on the three illnamed days of May by Berlin observations for eightysix years (Verhandl. des Vereins zur Beford. desGartenbaues, 1834, s. 377), and found a retrogression of temperatureamouuting to 292 Fahr. from the 11th to the 13th of May,

The Greek natural philosophers, who were but little disposed to pursue observations, but evinced inexhaustible fertility of imagination in giving the most various interpretation of half-perceived facts, have, however, left some hypotheses regarding shooting stars and meteoric stones which strikingly accord with the views now almost universally admitted of the cosmical process of these phenomena. Falling stars, says Plutarch, in his life of Lysander,[31] are,

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a period atwhich nearly the most rapid advance of heat takes place. It is muchto be desired that this phenomenon of depressed temperature, whichsome have felt inclined to attribute to the melting of the ice in thenortheast of Europe, should be also investigated in very remote spots,as in America, or im the southern hemisphere. (Comp. Bull. dei Acad.Inp. de St. Pétersbourg, 1843, t. i., No. 4.)

[31] Plot., Vite par. in Lysandro, cap. 22. The statement of Damackos (Daimachos), that for seventy days continuously there was a fiery cloud seen in the sky, emitting sparks like falling stars, and which then, sinking nearer to the earth, let fall the stone of gos Potamos, which, however, was only a small part of it, is extremely improbable, since the direction and velocity of the fire cloud would in that case

according to the opinion of some physicists, not eruptions of the ether, a fire extinguished in the air immediately after its ignition, nor yet an inflammatory combustion of the air, which is dissolved in large quantities in the upper regions of space, but these meteors are rather a fall of celestial bodies, which, in consequence of a certain intermission in the rotatory force, and by the impulse of some irregular movement, have been hurled down, not only

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of necessity have to remain for so many days the same as those of the earth; and this, in the fireball of the 19th of July, 1686, described by Halley (Trans., vol. xxix., p. 163), lasted only a few minutes. It is not altogether certain whether Daimachos, the writer, rep evoefeiac, was the same person as Daimachos of Platea, who was sent by Seleucus to India to the son of Androcottos, and who was charged by Strabo with being a speaker of lies (p.70, Casaub.). From another passage of Plutarch (Compar. Solonis c. Cop., cap. 5) we should almost believe that he was. At all events, we have here only the evidence of a very late author, who wrote a century and a half after the fall of aérolites occurred in Thrace, and whose authenticity is also doubted by Plutarch.

to the inhabited portions of the Earth, but also beyond it into the great ocean, where we cannot find them. Diogenes of Apollonia expresses himself still more explicitly. According to his views, Stars that are invisible, and, consequently, have no name, move in space together with those that are visible. These invisible stars frequently fall to the earth and are extinguished, as the story star which fell burning at ASgos Potamos. The Apollonian, who held all other stellar bodies, when luminous, to be of a pumice-like nature, probably grounded his opinions regarding shooting stars and meteoric masses on the doctrine of Anaxagoras the Clazomenian, who regarded all the bodies in the universe as fragments of rocks, which the fiery ether, in the force of its gyratory motion, had torn from the Earth and converted into stars. In the Ionian school, therefore, according to the testimony transmitted to us in the views of Diogenes of Apollonia,[32] aérolites and stars were ranged in one and the same class; both, when considered with reference to their primary origin, being equally telluric, this being understood only so far as the Earth was then regarded as a central body,[33] forming all

[32]Stob., ed. Heeren, i., 25, p. 508; Plut., de plac. Philos., ii., 13.

[33]The remarkable passage in Plut., de plac. Philos., ii., 13, runs thus Anaxagoras teaches that the surrounding ether is a fiery substance, which, by the power of its rotation, tears rocks from the earth, inflames them, and converts them into stars. Applying an ancient fable to illustrate a physical dogma, the Clazomenian appears to have ascribed the fall of the Nemzan Lion to the Peloponnesus from the Moon to such a rotatory or centrifugal force. (lian., xii., 7; Plut., de Facietn Orbe Lune, c. 24; Schol. ex Cod. Paris., in Apoll. Argon., lib. i., p. 498, ed. Schaef., t. fl., p. 40; Meineke, Annal. Alez., 1843, p 85.) Here, instead of stones from the Moon, we have an animal from the Moon According to an acute remark of Béckh, the ancient mythology of the Nemean lunar lion has an astronomical origin, and is symbolically connected in chronology with the cycle of intercalation of the lunar year, with the moon worship at Nema, and the

things around it in the same manner as we, according to our present views, suppose the planets of our system to have originated in the expanded atmosphere of another central body, the Sun. These views must not, therefore, be confounded with what is commonly termed the telluric or atmospheric origin of meteoric stones, nor yet with the singular opinion of Aristotle, which supposed the enormous mass of Aigos Potamos to have been raised by a hurricane. That arrogant spirit of incredulity, which rejects facts without attempting to investigate them, is in some cases almost more injurious than an unquestioning credulity. Both are alike detrimental to the force of investigation. Notwithstanding that for more than two thousand years the annals of different na-

games by which it was accompanied.

tions had recorded falls of meteoric stones, many of which had been attested beyond all doubt by the evidence of irreproachable eyewitnesses notwithstanding the important part enacted by the Batylia in the meteor worship of the ancients notwithstanding the fact of the companions of Cortez having seen an aérolite at Cholula which had fallen on the neighboring pyramid notwithstanding that califs and Mongolian chiefs had caused swords to be forged from recently fallen meteoric stones nay, notwithstanding that several persons had been struck dead by stones falling from heaven, as, for instance, a monk at Crema on the 4th of September, 1511, another monk at Milan in 1650, and two Swedish sailors on board ship in 1674, yet this great cosmical phenomenon remained almost wholly unheeded, and its intimate connection with other planetary systems unknown, until attention was drawn to the subject by Chladuni, who had already gained immortal renown by his on of the sound figures. He who is penetrated with a sense of this mysterious connection, and whose mind is open to deep impressions of nature, will feel himself moved by the deepest and most solemn emotion at the sight of every star that shoots across the vault of heaven, no less than at the glorious spectacle of meteoric evra in the November phenomenon or on St. Lawrence's day. Her emotion is suddenly revealed in the midst of nocturnal rest. The still radiance of the vault of heaven is for a moment animated with life and movement. In the mild radiance left on the track of the shooting star, imagination pictures the lengthened path of the meteor through the vault of heaven, while, everywhere around, the luminous astervids proclaim the existence of one common material universe.

If we compare the volume of the innermost of Saturn's satellites, or that of Ceres, with the immense volume of the Sun, all relations of magnitude vanish from our minds. The extinction of suddenly resplendent stars in Cassiopeia, Cygnus, and Serpentarius have already led to the assumption of other and nonluminous cosmical bodies. We now know that the meteoric asteroids, spherically agglomerated into small masses, revolve round the Sun, intersect, like comets, the orbits of the luminous larger planets, and become ignited either in the vicinity of our atmosphere or in its upper strata.

The only media by which we are brought in connection with other planetary bodies, and with all portions of the universe beyond our atmosphere, are light and heat (the latter of which can scarcely be separated from the former)[34], and those mysterious powers of attraction exercised by remote masses, according to the quantity of their constituents, upon our globe, the ocean, and the strata of our atmosphere. Another and different kind of cosmical, or, rather, material mode of contact is, however, opened to us, if we admit falling stars and meteoric stones to

[34]The following remarkable passage on the radiation of heat from the fixed stars, and on their low combustion and vitality—one of Kepler's many aspirations—occurs in the Paralipom. in Vitell. Astron. pars Optica, 1604, Propos. xxxii., p. 25: "Lucis proprium est calor, sicut omnia calefaciunt. De syderum luce claritatis ratio testatur, calorem universorum in minori esse proportione ad calorem unius solis, quam ut ab homine, cujus est certa caloris mensura, uterque simul percipi et judicari possit. De cincindularum lucula tenuissima negare non potes, quin cum calore sit. Vivant enim et moventur, hoc autem non sine calefactione perficitur. Sic neque putrescentium lignorum lux suo calore destituitur; nam ipsa putredo quidam lentus ignis est. Inest et stirpibus suus calor." (Compare Kepler, Epit. Astron. Copernicane, 1618, t. i. lib. i. c. 35).

be planetary asteroids. They not only act upon us merely from a distance by the excitement of luminous or calorific vibrations, or in obedience to the laws of mutual attraction, but they acquire an actual material existence for us, reaching our atmosphere from the remoter regions of universal space, and remaining on the earth itself. Meteoric stones are the only means by which we can be brought in possible contact with that which is foreign to our own planet. Accustomed to gain our knowledge of what is not telluric solely through measurement, calculations, and the deductions of reason, we experience a sentiment of astonishment at finding that we may examine, weigh, and analyze bodies that appertain to the outer world. This awakens, by the power of the imagination, a meditative, spiritual train of thought, where the untutored mind perceives only scintillations of light in the firmament, and sees in the blackened stone that falls from the exploded cloud nothing beyond the rough product of a powerful natural force. Although the asteroid swarms, on which we have been led, from special predilection, to dwell somewhat at length, approximate to a certain degree, in their inconsiderable mass and the diversity of their orbits, to comets, they present this essential difference from the latter bodies, that our knowledge of their existence is almost entirely limited to the moment of their destruction, that is, to the period when, drawn within the sphere of the Earth's attraction, they become luminous and ignite.

Chapter 8

Zodiacal Light

In order to complete our view of all that we have learned to consider as appertaining to our solar system, which now, since the discovery of the small planets, of the interior comets of short revolutions, and of the meteoric asteroids, is so rich and complicated in its form, it remains for us to speak of the ring of zodiacal light, to which we have already alluded. Those who have lived for many years in the zone of palms must retain a pleasing impression of the mild radiance with which the zodiacal light, shooting pyramidally upward, illumines a part of the uniform length of tropical nights. I have seen it shine with an intensity of light equal to the Milky Way in Sagittarius, and that not only in the rare and dry atmosphere of the summits of the Andes, at an elevation of from thirteen to fifteen thousand feet, but even on the boundless grassy plains, the llanos of Venezuela, and on the seashore, beneath the ever-clear sky of Cumana. This phenomenon was often rendered especially beautiful by the passage of light, fleecy clouds, which stood out in picturesque and bold relief from the luminous background. A notice of this aerial spectacle is contained in a passage in my journal, while I was on the voyage from Lima to the western coasts of Mexico. For three or four nights (between 10 and 14 north latitude) the zodiacal light has appeared in greater splendor than I have ever observed it. The transparency of the atmosphere must be remarkably great in this part of the Southern Ocean, to judge by the radiance of the stars and nebulous spots. From the 14th to the 19th of March a regular interval of three quarters of an hour occurred between the disappearance of the sun's disk in the ocean and the first manifestation of the zodiacal light, although the night was already perfectly dark. An hour after sunset it was seen in great brilliancy between Aldebaran and the Pleiades; and on the 18th of March it attained an altitude of 39 5. Narrow elongated clouds are scattered over the beautiful deep azure of the distant horizon, flitting past the zodiacal light as before a golden curtain. Above these, other clouds are from time to time reflecting the most brightly variegated colors. It seems a second sunset. On this side of the vault of heaven the lightness of the night appears to increase almost as much as at the first quarter of the moon. Toward 10 o'clock the zodiacal light generally becomes very faint in this part of the Southern Ocean, and at midnight have scarcely been able to trace a vestige of it. On the 16th of March, when most strongly luminous, a faint reflection was visible in the east. In our gloomy so-called "temperate" northern zone, the zodiacal light is only distinctly visible in the beginning of Spring, after the evening twilight, in the western part of the sky, and at the close of Autumn, before the dawn of day, above the eastern horizon.

It is difficult to understand how such a striking natural phenomenon could have failed to attract the attention of physicists and astronomers until the middle of the seventeenth century, or how it could have escaped the observation of the Arabian natural philosophers in ancient Bactria, on the Euphrates, and in the south of Spain. Almost equally surprising is the tardiness of observation

Figure 8.1: Centre of the Milky Way and zodiacal light above the platform of the Very Large Telescope (VLT) on Cerro Paranal. Author: ESO/B. Tafreshi (twanight.org). License: CC BY 4.0.

of the nebulous spots in Andromeda and Orion, first described by Simon Marius and Huygens. The earliest explicit description of the zodiacal light occurs in Childrey's Britannia Baconica[1],

[1]There is another thing which I recommend to the observation of mathematical men, which is, that in February, and for a little before and a little after that month (as I have observed several years together), about six in the evening, when the twilight has almost deserted the horizon, you shall see a plainly discernible way of the twilight striking up toward the Pleiades, and seeming almost to touch them. It is so observed any clear night, but it is best illac nocte. There is no such way to be observed at any other time of the year (that I can perceive), nor any other way at that time to be perceived darting up elsewhere; and I believe it has been, and will be constantly visible at that time of the year; but what the cause of it in nature should be, I cannot yet imagine, but leave it to future inquiry. (Childrey, Britannia Baconica, 1661, p. 183.) This is the first view and a simple description of the phenomenon. (Cassini, Découverte de la Lumière Céleste qui parott dans le Zodiaque, in the Mém. de l'Acad., t. viii., 1730, p. 276. Mairan, Traité Phys. de l'Aurore Boréale, 1754, p.16.) In this remarkable work by Childrey, there are very clear accounts of the epochs of maximum and minimum diurnal and annual temperatures, and of the retardation of the extremes of the effects in meteorological processes. It is, however, to be regretted that our Baconian philosophy-loving author, who was Lord Henry Somerset's chap-

in the year 661. The first observation of the phenomenon may have been made two or three years prior to this period; but, notwithstanding, the merit of having (in the spring of 1683) been the first to investigate the phenomenon in all its relations in space is incontestably due to Dominicus Cassini. The light which he saw at Bologna in 1668, and which was observed at the same time in Persia by the celebrated traveler Chardin (the court astrologers of Ispahan called this light, which had never before been observed, nyzek, a small lance), was not the zodiacal light, as has often been as-

lain, fell into the same error as Bernardin de St. Pierre and regarded the Earth as elongated at the poles (see p. 148). At first, he believes that the Earth was spherical but supposes that the uninterrupted and increasing addition of layers of ice at both poles has changed its figure; and that, as the ice is formed from water, the quantity of that liquid is everywhere diminishing.

serted,[2] but the enormous tail of a comet,

[2]Dominicus Cassini (Mém. de l'Acad., t. viii, 1730, p. 188), and Mairan (Aurore Bor., p. 16), have even maintained that the phenomenon observed in Persia in 1668 was the zodiacal light. Delambre (Hist. de Astron. Moderne, t. ii., p. 742), in very decided terms, ascribes the discovery of this light to the celebrated traveler Chardin; but in the Couronnement de Soliman, and in several passages of the narrative of his travels (éd. de Langlès, t. iv., p. 326; t. x., p. 97), he only applies the term niazouk (nyzek), or petite lance, to the great and famous comet which appeared over nearly the whole world in 1668, and whose head was so hidden in the west that it could not be perceived on the horizon of Ispahan (Atlas du Voyage de Chardin, Tap. iv.; from the observations at Schiraz). The head or nucleus of the comet was, however, visible in the Brazils and in India (Pingré, Cométogr., t. ii., p. 22). Regarding the conjectured identity of the last great comet of March 1843 with this, which Cassini mistook for the zodiacal light, see Schum., Astr. Nachr., 1843, No. 476 and 480. In Persian, the term nizehiteschin (fiery spears or lances) is also applied to the rays of the rising or setting sun, in the same way as nayazik, according to Freytag's Arabic Lexicon, signifies "stelle cadentes." The comparison of comets to lances and swords was, however, very common in all languages in the Middle Ages. The great comet of 1500, which was visible from April to June, was always termed by the Italian writers of that time "el Signor Astone" (see my Examen Critique de l'Hist. de la Géographie, t. v., p. 80). All the hypotheses that have been advanced to show that Descartes (Cassini, p. 230; Mairan, p. 16), and even Kepler (Delambre, t. i., p. 601), were acquainted with the zodiacal light, appear to me altogether un-

whose head was concealed in thevapory mist of the horizon, and which, from its length andappearance, presented much similarity to the great eomet of1843. We may conjecture, with much probability, that theremarkable light on the elevated

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tenable. Descartes (Principes, iii., art. 136, 137) is very obscure in his remarks on comets, observing that their tails are formed by oblique rays, which, falling on different parts of the planetary orbs, strike the eye laterally by extraordinary refraction, and that they might be seen morning and evening, like a long beam, when the Sun is between the comet and the Earth. This passage no more refers to the zodiacal light than those in which Kepler (Eyit. Astron. Copernicana, t.i., p. 57, and t. ii., p. 893) speaks of the existence of a solar atmosphere (limbus circa solem, coma lucida), which, in eclipses of the Sun, prevents it from being quite night; and even more uncertain, or indeed erroneous, is the assumption that the "trabes quas doxove vocant" (Plin., ii., 26 and 27) had reference to the tongue-shaped rising zodiacal light, as Cassini (p. 231, art. xxxi.) and Mairan (p. 15) have maintained. Among the ancients, the trabes are associated with the bolides (ardores et faces) and other fiery meteors, and even with long-barbed comets. (Regarding doxdc, doxiac, doxityc, see Schiifer, Schol. Par. ad Apoll. Rhod., 1813, t. ii., p. 206; Psendo Aristot., de Mundo, 2, 9; Comment. Alex. Joh. Philop. et Olympin Aristot. Meteor., lib. i., cap. vii., 3, p. 195, Ideler; Seneca, Nat. Quest., i., nh plains of Mexico, seen forforty nights consecutively in 1509, and observed in the easternhorizon rising pyramidally from the earth, was the zodiacallight. I found a notice of this phenomenon in an ancient Aztec MS., the Codex TellerianoRemensis,[3] preserved in theRoyal Library at

[3]Humboldt, Monwmens des Peuples Indigénes de l Amérique, t. ii..p 301. The rare manuscript which belonged to the Archbishop ofRheims, Le Tellier, contains various kinds of extracts from an Aztecritual, an astrological calendar, and historical annals, extending from1197 to 1549, and embracing a notice of different natural phenomena,epochs of earthquakes and comets (as, for instance, those of 1490 and1529), and of (which aré important in relation to Mexican chronology)solar eclipses. In Camargos manuscript Historia de Tiascala, the lightrising in the east almost to the zenith is, singularly enough, describedas sparkling, and as if sown with stars. The description of thisphenomenon, which lasted forty days, can not in any way apply to yolcanic eruptions of Popocatepetl, which lies very near, in the southeast.ern direction. (Prescott, History of the Conquest of Mexico, vol. i., p.284.) Later commentators have corfounded this phenomenon, whichMontezuma regarded as a warning of his misfortunes, with the estrellaque humeava (literally, which spring forth; Mexican choloa, to leap orspring forth). With respect to the connection of this vapor with thestar Citlal

Paris.

This phenomenon, whose primordial antiquity can scarcely be doubted, and which was first noticed in Europe by Childrey and Dominicus Cassini, is not the luminous solar atmosphere itself, since this cannot, in accordance with mechanical laws, be more compressed than in the relation of 2 to 3, and consequently cannot be diffused beyond 1/3 of Mercury's heliocentric distance. These same laws teach us that the altitude of the extreme boundaries of the atmosphere of a cosmical body above its equator, that is to say, the point at which gravity and centrifugal force are in equilibrium, must be the same as the altitude at which a satellite would rotate round the central body simultaneously with the diurnal revolution

Choloha (Venus) and with the mountain of the star (Citlaltepetl, the volcano of Orizaba), see my Monumens, t. ii., p. 303.

of the latter.[4] This limitation of the solar atmosphere in its present concentrated condition is especially remarkable when we compare the central body of our system with the nucleus of other nebulous stars. Herschel has discovered several, in which the radius of the nebulous matter surrounding the star appeared at an angle of 150. On the assumption that the parallax is not fully equal to 1, we find that the outermost nebulous layer of such a star must be 150 times further from the central body than our Earth is from the Sun. If, therefore, the nebulous star were to occupy the place of our Sun, its atmosphere would not only include the orbit of Uranus, but even extend eight times beyond it.[5]

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[4] Laplace, Expos. du Syst. du Monde, p. 270; Mécanique Céleste, t. ii, p. 169 and 171; Schubert, Asér., bd. iii., 206.

[5] Arago, in the Annuaire, 1842, p. 408. Compare Sir John Her-

Considering the narrow limitation of the Sun's atmosphere, which we have just described, we may with much probability regard the existence of a very compressed annulus of nebulous matter,[6]" re-

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schel's considerations on the volume and faintness of light of planetary nebulae, in Mary Somerville's Connection of the Physical Sciences, 1835, p. 108. The opinion that the Sun is a nebulous star, whose atmosphere presents the phenomenon of zodiacal light, did not originate with Dominicus Cassini, but was first promulgated by Mairan in 1730 (Traité de l'Aurore Bor., p. 47 and 263; Arago, in the Annuaire, 1842, p. 412). It is a renewal of Kepler's views.

[6]Dominicus Cassini was the first to assume, as did subsequently Laplace, Schubert, and Poisson, the hypothesis of a separate ring to explain the form of the zodiacal light. He says distinctly, "If the orbits of Mercury and Venus were visible (throughout their whole extent), we should invariably observe them with the same figure and in the same position with regard to the Sun, and at the same time of the year with the zodiacal light." (Afém. del Acad., t. viii., 1730, p. 218, and Biot, in the Comptes Rendus, 1836, t. iii., p. 666.) Cassini believed that the nebulous ring of zodiacal light consisted of innumerable small planetary bodies revolving round the Sun. He even went so far as to believe that the fall of fireballs might be connected with the passage of the Earth through the zodiacal nebulous ring. Olmsted, and especially Biot (op. cit., p. 673), have attempted to establish its connection with the November phenomena, a connection

volving freely in space between the orbits of Venus and Mars, as the material cause of the zodiacal light. As yet we certainly know nothing definite regarding its actual material dimensions; its augmentation[7] by emanations from the tails of myriads of comets that come within the Sun's vicinity; the singular changes affecting its expansion, since it sometimes does not appear to extend beyond our Earth's orbit; or, lastly, regarding its conjectural intimate connection with the more condensed cosmical vapor in the vicinity of the Sun. The nebulous particles composing this ring, and revolving round the Sun in accordance with planetary laws, may ei-

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which Olbers doubts. (Schum., Jahrb., 1837, 8.281.) Regarding the question whether the place of the zodiacal light perfectly coincides with that of the Sun's equator, see Houzeau, in Schum., Astr. Nachr., 1843, No 492, 8. 190.

[7]Sir John Herschel, Astron., 487. i

ther be self-luminous or receive light from that luminary. Even in the case of a terrestrial mist (and this fact is very remarkable), which occurred at the time of the new moon at midnight in 1743, the phosphorescence was so intense that objects could be distinctly recognized at a distance of more than 600 feet.

I have occasionally been astonished, in the tropical climatesof South America, to observe the variable intensity of thezodiacal light. As I passed the nights, during many months,in the open air, on the shores of rivers and on llanos, I enjoyed ample opportunities of carefully examining this phenomenon. When the zodiacal light had been most intense, I haveobserved that it would be perceptibly weakened for a fewminutes, until it again suddenly shone forth in full brilliancyIn some few instances I have thought that I could perceivenot exactly a reddish coloration, nor the lower portion darkenedin an arclike form, nor evena scintillation, as Mairan affirmshe has observedbut a kind of flickering and wavering ofthe light.[8] Must we suppose that changes are actually inprogress in the nebulous ring or is it not more probable that,although I could not, by my meteorological instruments, detect any change of heat or moisture near the ground, andsmall stars of the fifth and sixth magnitudes appeared to shinewith equally undiminished intensity of light,

[8] Arago, in the Annuaire, 1832, p. 246. Several physical facts appear to indicate that, in a mechanical separation of matter into its smallest particles, if the mass be very small in relation to the surface, theelectrical tension may increase sufficiently for the production of light.and heat. Experiments with a large concave mirror have not hitherto given any positive evidence of the presence of radiant heat in the zoCiecil light. (Lettre de M. Matthiessen 4 M. Arago, in the ComptesRendus, t. Xvi., 1843, Avril, p. 687.) ;

processes of condensation maybe going on in the uppermost strata of the air,by means of which the transparency, or, rather, the reflectionof light, may be modified in some peculiar and unknown manner An assumption of the existence of such meteorologicalcauses on the confines of our atmosphere is strengthened bythe sudden flash and pulsation of light, which, accordingto the acute observations of Olbers, vibrated for several seconds through the tail of a comet, which appeared during thecontinuance of the pulsations of light to be lengthened by several degrees, and then again contracted.[9] As, however, thesep-

[9]What you tell me of the changes of light in the zodiacal light,and of the causes to which you ascribe such changes within the tropics, is of the greater interest to me, since I have been for a long timepast particularly attentive, every spring, to this phenomenon in ournorthern latitudes. I, too, have always believed that the zodiacal lightrotated ; but I assumed (contrary to Poissons opinion, which you havecommunicated to me) that it completely extended to

the Sun, withconsiderably augmenting brightness. The lighit circle which, in totalsolar eclipses, is seen surrounding the darkened Sun, I have regardedas the brightest portion of the zodiacal light. I have convinced myself that this light is very different in different years, often for severalsuccessive years being very bright and diffused, while in other yearsit is scarcely perceptible. I think that I find the first trace of an allusion to the zodiacal light in a letter from Rothmann to Tycho, in whichhe mentions that in spring he has observed the twilight did not closeuntil the sun was 24 below the horizon. Rothmann must certainlyhave confounded the disappearance of the setting zodiacal light in thevapors of the western horizon with the actual cessation of twilight. 1have failed to observe the pulsations of the light, probably on accountof the faintness with which it appears in these countries. You are,however, certainly right in ascribing those rapid variations in the lightof the heavenly bodies, which you have perceived in tropical climates,to our own atmosphere, and especially to its higher regions. This ismost strikingly seen in the tails of large comets. We often observe,especially in the clearest weather, that these tails exhibit pulsations,commencing from the head, as being the lowest part, and vibrating inane or two seconds through the entire tail, which thus appears rapidlyto become some degrees aoe but again as rapidly contracts. Thatthese undulations, which were formerly noticed with attention byRobert Hooke, and in more recent times by Schréter and Chladni, donot actually occur in the tails of the comets, but are produced by our at.mosphere, is obvious when we recollect that the individual parts ofthose tails (which are many millions of miles in length) lie at very different distances from us, and that the light from their extreme pointscan only reach us at intervals arate particles of a comets tail, measuring millions of miles, are very unequally distant from the earth, it is not possible,according to the laws of the velocity and transmission of light,that we should be able, in so short a period of time, to pereeive any actual changes in a cosmical body of such vast extent. These considerations in no way exclude the reality ofthe changes that have been observed in the emanations fromthe more condensed envelopes around the nucleus of a comet,nor that of the sudden irradiation of the zo-

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of time which differ several minutes from .one another. Whether what you saw on the Orinoco, not at intervalsof seconds, but of minutes, were actual coruscations of the zodiacallight, or whether they belonged exclusively to the upper strata of outatmosphere, I will not attempt to decide; neither can I explain theremarkable lightness of whole nights, nor the anomalous augmentationand prolongation of the twilight in the year 1831, particularly if, as hasbeen remarked, the lightest part of these singular twilights did not coincide with the Suns place below the horizon. (From a letter writtexby Dr. Olbers to myself, and dated Bremen, March 26th, 1833.)

diacal light frommternal molecular motion, nor of the increased or diminishedreflection of light in the cosmical vapor of the luminous ring,but should simply be the means of drawing our attention tothe differences existing between that which appertains to theair of heaven (the realms of universal space) and that whichbelongs to the strata of our terrestrial atmosphere. It is notpossible, as wellattested facts prove, perfectly to explain theoperations at work in the muchcontested upper boundaries ofour atmosphere. The extraordinary lightness of whole nightsin the year 1831, during which small print might be read atmidnight in the latitudes of Italy and the north of Germany,is a fact directly at variance with all that we know, according to the most recent and acute researches on the erepusculartheory, and of the height of the atmosphere.[10] The phenomeua of light depend upon conditions still less understood, andtheir variability at twilight, as well as in the zodiacal light,excite our astonishment.

[10]Biot, Traité d Astron. Physique, 3eme éd., 1841, t. i., p. 171, 238,and 312.

Chapter 9

Translatory Motion of The Solar System

We have hitherto considered that which belongs to our solar system, that world of material forms governed by the Sun, which includes the primary and secondary planets, comets of short and long periods of revolution, meteoric asteroids, which move thronged together in streams, either sporadically or in closed rings, and finally a luminous nebulous ring that revolves around the Sun in the vicinity of the Earth, and for which, owing to its position, we may retain the name of zodiacal light. Everywhere the law of periodicity governs the motions of these bodies, however different may be the amount of tangential velocity or the quantity of their agglomerated material parts; the meteoric asteroids which enter our atmosphere from the external regions of universal space are alone arrested in the course of their planetary revolution and retained within the sphere of a larger planet. In the solar system, whose boundaries determine the attractive force of the central body, comets are made to revolve in their elliptical orbits at a distance 44 times greater than that of Uranus; nay, in those comets whose nucleus appears to us, from its inconsiderable mass, like a mere passing cosmical cloud, the Sun exercises its attractive force on the outermost parts of the emanations radiating from the tail over a space of many millions of miles. Central forces, therefore, at once constitute and maintain the system.

Our Sun may be considered as at rest when compared to all the large and small, dense and almost vaporous cosmic bodies that appertain to and revolve around it; but it actually rotates round the common center of gravity of the whole system, which occasionally falls within itself, that is to say, remains within the material circumference of the Sun, whatever changes may be assumed by the positions of the planets. A very different phenomenon is that presented by the translatory motion of the Sun, that is, the progressive motion of the center of gravity of the whole solar system in universal space. Its velocity is such[1] that, according to Bessel, the relative motion of the Sun, and that of 61 Cygni, is not less in one day than 3,336,000 geographical miles. This change of the entire solar system would remain unknown to us, if the admirable exactness of our astronomical instruments of measurement, and the advancement recently made in the art of observing, did not cause our advance toward remote stars to be perceptible, like an approximation to the objects of a distant shore in apparent motion. The proper

[1]Bessel, in Schum., Jahrb. fur 1839, 8.51; probably four millionsof miles daily, in a relative velocity of at the least 3,336,000 miles, ormore than double the velocity of revolution of the Earth in her orbitsound the Sun.

motion of the star 61 Cygni, for instance, is so considerable, that it has amounted to a whole degree in the course of 700 years.

The amount or quantity of these alterations in the fixedstars (that is to say, the changesin the relative position ofselfluminous stars toward each other), can be determinedwith a greater degree of certainty than we are able to attachto the genetie explanation of the phenomenon. After takinginto consideration what is due to the precession of the equinoxes, and the nutation of the earths axis produced by theaction of the Sun and Moon on the spheroidal figure of ourglobe, and what may be ascribed to the transmission of light,that is to say, to its aberration, and to the parallax formed bythe diametrically opposite position of the Earth in its courseround the Sun, we still find that there is a residual portion of the annual motion of the fixed stars due to the translationof the whole solar system in universal space, and to the trueproper motion of the stars. The difficult problem of numerically separating these two elements, the true and the apparent motion, has beeneflected by the careful study of the direction of the motion of certain individual stars, and by theconsideration of the fact that, if all the stars were in.a stateof absolute rest, they would appear perspectively to recedefrom the point in space toward which the Sun was directingits course. But the ultimate result of this investigation, confirmed by the calculus of probabilities, is, that our solar system and the stars both change their places in space. According to the admirable researches of Argelander at Abo, whohas extended and more perfectly developed the work begun byWilliam Herschel and Prevost, the Sun moves in the direction of the constellation Hercules, and probably, from thecombination of the observations made of 537 stars, toward apoint lying (at the equinox of 17925) at 257 497 R.A., and28 497 N.D. It is extremely difficult, in investigations ofthis nature, to separate the absolute from the relative motion,and to determine what is alone owing to the solar system.[2]

[2]Regarding the motion of the solar system, according to Bradley,Tobias Mayer, Lambert, Lalande, and William Herschel, see Arago, inthe Annuaire, 1842, p. 388399 ; Argelander, in Schum., Astron. Nachr.,No. 363, 364, 398, and in the treatise Von der eigenen Bewegung desSonnensystems (On the proper Motion of the Solar em, 1837, s. 43,respecting Perseus as the central body of the whole stellar stratum,likewise Otho Struve, in the Bull. del Acad. de St. Pétersb., 1842, t. x.,No. 9, p. 187139. The lastnamed astronomer has found, by a morerecent combination, 261 23 R.A. 37 36 Decl. for the direction ofthe Suns motion; and, taking the mean of his own results with that ofArgelander, we have, by a combination of 797 stars, the formula 259Y R.A. 34 36 Decl.

If we consider the proper, and not the perspective motions of the stars, we shall find many that appear to be distributed in groups, having an opposite direction; and facts hitherto observed do not, at any rate, render it a necessary assumption that all parts of our starry stratum, or the whole of the stellar islands filling space, should move round one large unknown luminous or nonluminous central body. The tendency of the human mind to investigate ultimate and highest causes certainly inclines the intellectual activity, no less than the imagination of mankind, to adopt such an hypothesis. Even the Stagirite proclaimed that every thing which is moved must be referable to a motor, and that there would be no end to the concatenation of causes if there were not one primordial immovable motor.[3]

The manifold translatory changes of the stars, not those produced by the parallaxes at which they are seen from the changing position of the spectator, but the true changes constantly going on in the regions of space, afford us incontrovertible evidence of the dominion of the laws of attraction in the remotest regions of space, beyond the limits of our solar system. The existence of these laws is revealed to us by many phenomena, as, for instance, by the motion of double stars, and by the amount of retarded or accelerated motion in different parts of their elliptic orbits. Human inquiry need no longer pursue this subject in the domain of vague conjecture, or amid the undefined analogies of the ideal world; for even here the progress made in

[3] Aristot., de Calo, iii., 2, p. 301, Bekker; Phys., viii., 5, p. 256.

the method of astronomical observations and calculations has enabled astronomy to take up its position on a firm basis. It is not only the discovery of the astounding numbers of double and multiple stars revolving round a center of gravity lying outside their system (2800 such systems having been discovered up to 1837), but rather the extension of our knowledge regarding the fundamental forces of the whole material world, and the proofs we have obtained of the universal empire of the laws of attraction, that must be ranked among the most brilliant discoveries of the age. The periods of revolution of colored stars present the greatest differences; thus, in some instances, the period extends to 43 years, as in 7 of Corona, and in others to several thousands, as in 66 of Cetus, 38 of Gemini, and 100 of Pisces. Since Herschel's measurements in 1782, the satellite of the nearest star in the triple system of of Cancer has completed more than one entire revolution. By a skillful combination of the altered distances and angles of position,[4] the elements of these orbits may be found, conclusions drawn regarding the absolute distance of the double stars from the Earth, and comparisons made between their mass and that of the Sun. Whether, however, here and in our solar system, quantity of matter is the only standard of the amount of attractive force, or whether specific forces of attraction proportionate to the mass may not at the same time come into operation, as Bessel was the first to conjecture, are questions whose

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[4]Savary, in the Connaissance des T'ems, 1830, p. 56 and 163. Encke,Berl. Jahrb., 1832, 8. 253, c. Arago, in the Annuaire, 1834, p. 260,295. John Herschel, in the Memoirs of the Astronom. Soc., vol. v., p. 171.

practical solution must be left to future ages.[5] Wherwe compare our Sun with the other fixed stars, that is, with other self-uminous Suns in the lenticular starry stratum of whichour system forms a part, we find, at least in the case of some,that channels are opened to us, which may lead, at all events,to an approximate and limited knowledge of their relativedistances, volumes, and masses, and of the velocities of theirtranslatory motion. If we assume the distance of Uranusfrom the Sun to be nineteen times that of the Earth, that isto say, nineteen times as great as that of the Sun from theEarth, the central bedy of our

[5]Bessel, Untersuchung. des Theils der planetarischen Storungen,welche aus der Bewegumg der Sonne entstehen (An Investigation of the portion of the Planetary Disturbances depending on the Motion of theSun) in Abk. der Berl. Akad. der Wissensch., 1824 (Mathem. Classe),s. 26. The question has been raised by John Tobias Mayer, in Comment. Soc. Reg. Gétting., 18041808, vol. xvi., p. 3168.

planetary system will be 11,900times the distance of Uranus from the star in the constellation Centaur, almost 31,300 from 61 Cygni, and 41,600 fromVega in the constellation Lyra. The comparison of the volume of the Sun with that of the fixed stars of the first magnitude is dependent upon the apparent diameter of the latterbodiesan extremely uncertain optical element. If even weassume, with Herschel, that the apparent diameter of Arcturus is only a tenth part of a second, it still follows that thetrue diameter of this star is eleven times greater than that ofthe Sun.[6] The distance of the star 61 Cygni, made knownby Bessel, has led approximately to a knowledge of the

[6]Philos. Trans. for 1803, p. 225. Arago, in the Annuaire, 1842, p.375. In order to obtain a clearer idea of the distances ascribed in arather earlier part of the text to the fixed stars, let us assume that theEarth is a distance of one foot from the Sun; Uranus is then 19 feet,and Vega Lyra is 158 geographical miles from it.

quantity of matter contained in this body as a double star. Notwithstanding that, since Bradleys observations, the portionof the apparent orbit traversed by this star is not sufficientlygreat to admit of our arriving with perfect exactness at thetrue orbit and the major axis of this star, it has been conjectured with much probability by the great Konigsberg astronomer,[7] that the mass of this double star can not be very considerably larger or smaller than half of the mass of the Sun.This result is from actual measurement. The analogies deduced from the relatively larger mass of those planets in oursolar system that are attended by satellites, and from the factthat Struve has discovered six times more double stars among the brighter than among the telescopic fixed stars, have ledother as-

[7]Bessel, in Schum., Jahrb., 1839, s. 53.

tronomers to conjecture that the average mass of thelarger number of the binary stars exceeds the mass of theSun.[8] We are, however, far from having arrived at generalresults regarding this subject. Our Sun, according to Argelander, belongs, with reference to proper motion in space, tothe class of rapidlymoving fixed stars.

The aspect of the starry heavens, the relative position of stars and nebula, the distribution of their luminous masses, the picturesque beauty, if I may so express myself, of the whole firmament, depend in the course of ages conjointly upon the proper motion of the stars and nebula, the translation of our solar system in space, the appearance of new stars, and the disappearance or sudden diminution in the intensity of the light of others, and, lastly

[8]Madler, Astron., 8. 476; also in Schum., Jahrb., 1839, 8 95.

and specially, on the changes which the Earth's axis experiences from the attraction of the Sun and Moon. The beautiful stars in the constellation of the Centaur and the Southern Cross will at some future time be visible in our northern latitudes, while other stars, as Sirius and the stars in the Belt of Orion, will in their turn disappear below the horizon. The places of the North Pole will successively be indicated by the stars 3 and a Cephei, and 6 Cygni, until after a period of 12,000 years, Vega in Lyra will shine forth as the brightest of all possible pole stars. These data give us some idea of the extent of the motions which, divided into infinitely small portions of time, proceed without intermission in the great chronometer of the universe. If for a moment we could yield to the power of fancy, and imagine the acuteness of our visual organs to be made equal with the extremest bounds of telescopic vision, and bring together that which is now divided by long periods of time, the apparent rest that reigns in space would suddenly disappear. We should see the countless host of fixed stars moving in thronged groups in different directions; nebulae wandering through space, and becoming condensed and dissolved like cosmical clouds; the veil of the Milky Way separated and broken up in many parts, and motion ruling supreme in every portion of the vault of heaven, even as on the Earth's surface, where we see it unfolded in the germ, the leaf, and the blossom, the organisms of the vegetable world. The celebrated Spanish botanist Cavanilles was the first who entertained the idea of seeing grass grow, and he directed the horizontal micrometer threads of a powerfully magnifying glass at one time to the apex of the shoot of a bambusa, and at another on the rapidly growing stem of an American aloe (Agave Americana), precisely as the astronomer places his cross of network against a culminating star. In the collective life of physical nature, in the organic as in the sidereal world, all things that have been, that are, and will be, are alike dependent on motion.

Chapter 10

The Milky Way

Figure 10.1: Milky Way seen from Western Estonian coast. Author: Kristian Pikner. License: CC-BY 4.0

The breaking up of the Milky Way, of which I have just spoken, requires special notice. William Herschel, our safe and admirable guide to this portion of the regions of space, has discovered by his star gazing that the telescopic breadth of the Milky Way extends from six to seven degrees beyond what is indicated by our astronomical maps and by the extent of the sidereal radiance visible to the naked eye. The two brilliant nodes in which the branches of the zone unite, in the region of Cepheus and Cassiopeia, and in the vicinity of Scorpio and Sagittarius, appear to exercise a powerful attraction on the contiguous stars; in the most brilliant part, however, between α and γ Cygni, one half of the 330,000 stars that have been discovered in a breadth of 5 are directed toward one side, and the remainder to the other. It is in this part that Herschel supposes the layer to be broken up. The number of telescopic stars in the Milky Way uninterrupted by any nebulæis estimated at 18 million. In order, I will not say, to realize the greatness of this number, but, at any rate, to compare it with something analogous, I will call attention to the fact that there are not in the whole heavens more than about 8000 stars, between the first and the sixth magnitudes, visible to the naked eye. The barren astonishment excited by numbers and dimensions in space, when not considered with reference to applications engaging the mental and perceptive powers of man, is awakened in both extremes of the universe, in the celestial bodies as in the minutest animalcules.[1]

[1]Sir John Herschel, Astronom., 624; likewise in his Observations on nebulæand Clusters of Stars (Phil. Transact., 1833, Part ii., p 479,

A cubic inch of the polishing slate of Bilin contains, according to Ehrenberg, 40,000 million of the silicious shells of Galionelle.

The stellar Milky Way, in the region of which, according to Argelander's admirable observations, the brightest stars of the firmament appear to be congregated, is almost at right angles with another Milky Way, composed of nebulæ. The former constitutes, according to Sir John Herschel's views, an annulus, that is to say, an independent zone, somewhat remote from our lenticular-shaped starry stratum, and similar to Saturn's ring. Our planetary system lies in an eccentric direction, nearer to the region of the Cross than to the diametrically opposite point, Cassiopeia.[2] An imperfectly seen nebulous

fig. 25) We have here a brother system, bearing a real physical resemblance and strong analogy of structure to our own.

[2]Sir William Herschel, in the Philos. Transact. for 1817, Part ii., p.

spot, discovered by Messier in 1774, appeared to present a remarkable similarity to the form of our starry stratum and the divided ring of our Milky Way.[3] The Milky Way composed of nebulædoes not belong to our starry stratum, but surrounds it at a great distance without being physically connected with it, passing almost in the form of a large cross through the dense nebulæof Virgo, especially in the northern wing, through Coma Berenices, Ursa Major, Andromeda's girdle, and Pisces Bo-

328. t Arago, in the Annuaire, 1842, p. 459. Sir John Herschel, in a letter from Feldhuysen, dated Jan. 13th, 1836. Nicholl, Architecture of the Heavens, 1838, p. 22. (See, also, some separate notices by Sir William Herschel on the starless space which separates us by a great distance from the Milky Way, in the Philos. Transact. for 1817, Part ii., p. 328.)

[3]Sir William Herschel, in the Phil. Transact. for 1785, Part i., p. 257. Sir John Herschel, Astron., 616. (The nebulous region of the heavens forms a nebulous Milky Way, composed of distinct nebulæ, as the other of stars. The same observation was made in a letter he addressed to me in March, 1829.) Sir John Herschel, Astron., 585.

reales. It probably intersects the stellar Milky Way in Cassiopeia, and connects its dreary poles (rendered starless from the attractive forces by which stellar bodies are made to agglomerate into groups) in the least dense portion of the starry stratum.

We see from these considerations that our starry cluster, which bears traces in its projecting branches of having been subject in the course of time to various metamorphoses, and evinces a tendency to dissolve and separate, owing to secondary centers of attraction, is surrounded by two rings, one of which, the nebulous zone, is very remote, while the other is nearer, and composed of stars alone. The latter, which we generally term the Milky Way, is composed of nebulous stars, averaging from the tenth to the eleventh degree of magnitude, but appearing, when considered individually, of very different magnitudes, while isolated starry clusters (starry swarms) almost always exhibit throughout a character of great uniformity in magnitude and brilliancy.

In whatever part the vault of heaven has been pierced by powerful and far-penetrating telescopic instruments, stars or luminous nebulæare everywhere discoverable, the former, in some cases, not exceeding the twentieth or twenty-fourth degree of telescopic magnitude. A portion of the nebulous vapor would probably be found resolvable into stars by more powerful optical instruments. As the retina retains a less vivid impression of separate than of infinitely near luminous points, less strongly marked photometric relations are excited in the latter case, as

Arago has recently shown.[4] The definite or amorphous cosmical vapor so universally diffused, and which generates heat through condensation, probably modifies the transparency of the universal atmosphere, and diminishes that uniform intensity of light which, according to Halley and Olbers, should arise if every point throughout the depths of space were filled by an infinite series of stars.[5] The assumption of such a distribution in space is, however, at variance with observation, which shows us large starless regions of space, openings in the heavens, as William Herschel terms them, one four degrees in width, in Scorpio, and another in Serpentarius. In the vicinity of both, near their margin, we find unresolvable nebulæ, of

[4]Arago, in the Annuaire, 1842, p. 282-285, 409-411, and 439-442.

[5]Olbers, on the transparency of celestial space, in Bode's Jahré., 1826, s. 110-121.

which that on the western edge of the opening in Scorpio is one of the most richly thronged of the clusters of small stars by which the firmament is adorned. Herschel ascribes these openings or starless regions to the attractive and agglomerative forces of the marginal groups.[6] They are parts of our starry stratum, says he, with his usual graceful animation of style, that have experienced great devastation from time. If we picture to ourselves the telescopic stars lying behind one another as a starry canopy spread over the vault of heaven, these starless regions in Scorpio and Serpentarius may, I think, be regarded as tubes through which we may look into the remotest depths of space. Other stars

[6]An opening in the heavens, William Herschel, in the Phil. Trans. for 1785, vol. lxxv., Part i., p. 256. Le Frangais Lalande, in the Connaiss. des T'ems pour l'An. VIII., p. 383. Arago, in the Annuaire, 1842, p. 425.

may certainly lie in those parts where the strata forming the canopy are interrupted, but these are unattainable by our instruments. The aspect of fiery meteors had led the ancients likewise to the idea of clefts or openings (chasmata) in the vault of heaven. These openings were, however, only regarded as transient, while the reason for their being luminous and fiery, instead of obscure, was supposed to be owing to the translucent illuminated ether which lay beyond them.[7] Derham, and even Huygens, did not appear disinclined to explain in a similar manner the mild radiance of the nebulæ.[8]

[7] Aristot., Meteor., ii., 5, 1. Seneca, Natur. Quest., i., 14, 2. Coelum discessisse, in Cic., de Divin., i., 43.

[8] Arago, in the Annuaire, 1842, p. 429.

Chapter 11

Starless Openings

WHEN we compare the stars of the first magnitude, which, on average, are certainly the nearest to us, with the nonnebulous telescopic stars, and further, when we compare the nebulous stars with unresolvable nebulæ, for instance, with the nebula in Andromeda, or even with the so-called planetary nebulous vapor, a fact is made manifest to us by the consideration of the varying distances and the boundlessness of space, which shows the world of phenomena, and that which constitutes its causal reality, to be dependent upon the propagation of light. The velocity of this propagation is, according to Struve's most recent investigations, 166,072 geographical miles in a second, consequently almost a million times greater than the velocity of sound. According to the measurements of Maclear, Bessel, and Struve, of the parallaxes and distances of three

Figure 11.1: Starless Core L1014. Author: NASA. Public domain.

fixed stars of very unequal magnitudes (a Centauri, 16 Cygni, and Lyre), a ray of light requires respectively 3, 93, and 12 years to reach us from these three bodies. In the short but memorable period between 1572 and 1604, from the time of Cornelius Gemma and Tycho Brahe to that of Kepler, three new stars suddenly appeared in Cassiopeia and Cygnus, and in the foot of Serpentarius. A similar phenomenon exhibited itself at intervals in 1670, in the constellation Vulpis. In recent times, even since 1837, Sir John Herschel has observed, at the Cape of Good Hope, the brilliant star 7 in Argo increase in splendor from the second to the first magnitude.[1] These events in the universe

[1] In December, 1837, Sir John Herschel saw the star 7 Argo, which till that time appeared as of the second magnitude, and liable to change, rapidly increase till it became of the first magnitude. In January, 1838, the intensity of its light was equal to that of Centauri.

belong, however, with reference to their historical reality, to other periods of time than those in which the phenomena of light are first revealed to the inhabitants of the Earth. They reach us like the voices of the past. It has been truly said that with our large and powerful telescopic instruments we penetrate alike through the boundaries of time and space. We measure the former through the latter, for in the course of an hour a ray of light traverses over a space of 592 million miles. While, according to the theogony of Hesiod, the dimensions of the universe were supposed to be expressed by the time occupied by bodies in falling to the ground (the brazen anvil was not more than nine days and nine nights in falling from

According to our latest information, Maclear, in March, 1843, found it as bright as Canopus; and even a Crucis looked faint by 7 Argo.

heaven to earth), the elder Herschel was of the opinion[2] that light required almost two million years to pass to the Earth from the remotest luminous vapor reached by his forty-foot reflector. Much, therefore, has vanished long before it is rendered visible to us. Much that we see was once differently arranged from what it now appears. The aspect of the starry heavens presents us with the spectacle of that which is only apparently simultaneous, and however much we may endeavor, by the aid of optical instruments, to bring the mildly radiant vapor of nebulous masses or the faintly glimmering starry clusters

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[2]Hence it follows that the rays of light of the remotest nebulæ must have been almost two million years on their way, and that consequently, so many years ago, this object must already have had an existence in the sidereal heaven, in order to send out those rays by which we now perceive it. William Herschel, in the Phil. Trans. for 1802, p. 498. John Herschel, Astroz., 590. Arago, in the Annuaire, 1842, p. 334, 359, and 382-385.

nearer, and diminish the thousands of years interposed between us and them, that serve as a criterion of their distance, it still remains more than probable, from the knowledge we possess of the velocity of the transmission of luminous rays, that the light of remote heavenly bodies presents us with the most ancient perceptible evidence of the existence of matter. It is thus that the reflective mind of man is led from simple premises to rise to those exalted heights of nature, where, in the light-illumined realms of space, myriad of worlds are bursting into life like the grass of the night.[3]

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[3]From my brother's beautiful sonnet "Freiheit und Gesetz." (Wilhelm von Humboldt, Gesammelte Werke, bd. iv., 8. 358, No. 25.)

Chapter 12

Terrestrial Phenomena

FROM the regions of celestial forms, the domain of Uranus, we will now descend to the more contracted sphere of terrestrial forces, to the interior of the Earth itself. A mysterious chain links together both classes of phenomena. According to the ancient signification of the Titanic myth,[1] the powers of organic life, that is to say, the great order of nature, depend upon the combined action of heaven and earth. If we suppose that the Earth, like all the other planets, originally belonged, according to its origin, to the central body, the Sun, and to the solar atmosphere that has been separated into nebulous rings, the same connection with this contiguous Sun, as well as with all the remote suns that shine in the firmament, is still revealed through the phenomena of light and radiating heat. The difference in the degree of these actions must not lead the physicist, in his delineation of nature, to forget the connection and the common empire of similar forces in the universe. A small fraction of telluric heat is derived from the regions of universal space in

[1] Otfried Miller, Prolegomena, 8. 373.

which our planetary system is moving, whose temperature (which, according to Fourier, is almost equal to our mean icy polar heat) is the result of the combined radiation of all the stars. The causes that more powerfully excite the light of the Sun in the atmosphere and in the upper strata of our air, that give rise to heat-engendering electric and magnetic currents, and awaken and genially vivify the vital spark in organic structures on the Earth's surface, must be reserved for the subject of our future consideration.

As we purpose for the present to confine ourselves exclusively within the telluric sphere of nature, it will be expedient to cast a preliminary glance over the relations in space of solids and fluids, the form of the Earth, its mean density, and the partial distribution of this density in the interior of our planet, its temperature and its electromagnetic tension. From the consideration of these relations in space, and of the forces inherent in matter, we shall pass to the reaction of the interior on the exterior of our globe; and to the special consideration of a universally distributed natural power - subterranean heat; to the phenomena of earthquakes, exhibited in unequally expanded circles of commotion, which are not referable to the action of dynamic laws alone; to the springing forth of hot wells; and, lastly, to the more powerful actions of volcanic The crust of the Earth, which may scarcely have been perceptibly elevated by the sudden and repeated, or almost uninterrupted shocks by which it has been moved from below, undergoes, nevertheless, great changes in the course of centuries in the relations of the elevation of solid portions, when compared with the surface of the liquid parts, and even in the form of the bottom of the sea. In this manner simultaneous temporary or permanent fissures are opened, by which the interior of the Earth is brought in contact with the external atmosphere. Molten masses, rising from an unknown depth, flow in narrow streams along the declivity of mountains, rushing impetuously onward, or moving slowly and gently, until the fiery source is quenched in the midst of exhalations, and the lava becomes incrusted, as it were, by the solidification of its outer surface. New masses of rocks are thus formed before our eyes, while the older ones are in their turn converted into other forms by the greater or lesser agency of Plutonic forces. Even where no disruption takes place the crystalline molecules are displaced, combining to form bodies of denser texture. The water presents structures of a totally different nature, as, for instance, concretions of animal and vegetable remains, of earthy, calcareous, or aluminous precipitates, agglomerations of finely pulverized mineral bodies, covered with layers of the silicious shields of infusoria, and with transported soils containing the bones of fossil animal forms of a more ancient world. The study of the strata which are so differently formed and arranged before our eyes, and of all that has been so variously dislocated, contorted, and upheaved, by mutual compression and volcanic force, leads the reflective observer, by simple analogies, to draw a comparison between the present and an age that has long passed. It is by a combination of actual phenomena, by an ideal enlargement of relations in space, and of the amount of active forces, that we are able to advance into the long sought and indefinitely anticipated domain of geognosy, which has only within the last half century been based on the solid foundation of scientific deduction.

It has been acutely remarked that, notwithstanding our continual employment of large telescopes, we are less acquainted with the exterior than with the interior of other planets, excepting, perhaps, our own satellite. They have been weighed, and their volume measured; and their mass and density are becoming known with constantly increasing exactness; thanks to the progress made in astronomical observation and calculation. Their physical character is, however, hidden in obscurity, for it is only in our own globe that we can be brought in immediate contact with all the elements of organic and inorganic creation. The diversity of the most heterogeneous substances, their admixtures and metamorphoses, and the ever-changing play of the forces called into action, afford to the human mind both nourishment and enjoyment, and open an immeasurable field of observation, from which the intellectual activity of man derives a great portion of its grandeur and power. The world of perceptive phenomena is reflected in the depths of the ideal world, and the richness of nature and the mass of all that admits of classification gradually become the objects of inductive reasoning.

I would here allude to the advantage of which I have already spoken, possessed by that portion of physical science whose origin is familiar to us, and is connected with our earthly existence. The physical description of celestial bodies, from the remotely glimmering nebulae with their suns, to the central body of our own system, is limited, as we have seen, to general conceptions of the volume and quantity of matter. No manifestation of vital activity is there presented to our senses. It is only from analogies, frequently from purely ideal combinations, that we hazard conjectures on the specific elements of matter, or on their various modifications in the different planetary bodies. But the physical knowledge of the heterogeneous nature of matter, its chemical differences, the regular forms in which its molecules combine together, whether in crystals or granules; its relations to the deflected or decomposed waves of light by which it is penetrated; to radiating, transmitted, or polarized heat; and to the brilliant or invisible, but not, on that account, less active phenomena of electromagnetism - all this inexhaustible treasure, by which the enjoyment of the contemplation of nature is so much heightened, is dependent on the surface of the planet which we inhabit, and more on its solid than on its liquid parts. I have already remarked how greatly the study of natural objects and forces, and the infinite diversity of the sources they open for our consideration, strengthen the mental activity, and call into action every manifestation of intellectual progress. These relations require, however, as little comment as that concatenation of causes by which particular nations are permitted to enjoy a superiority over others in the exercise of a material power derived from their command of a portion of these elementary forces of nature.

If, on the one hand, it were necessary to indicate the difference existing between the nature of our knowledge of the Earth and of that of the celestial regions and their contents, I am no less desirous, on the other hand, to draw attention to the limited boundaries of that portion of space from which we derive all our knowledge of the heterogeneous character of matter. This has been somewhat inappropriately termed the Earth's crust; it includes the strata most contiguous to the upper surface of our planet, and which have been laid open before us by deep fissure-like valleys, or by the labors of man, in the bores and shafts formed by miners. These labors [2] do not extend beyond the leve.

[2] In speaking of the greatest depths within the Earth reached by human labor, we nrist recollect that there is a difference between the absolute depth (that is to say, the depth below the Earths surface

at that point) and the relative depth (or that beneath the level of the sea). Thegreatest relative depth that man has hitherto reached is probably thepare at the new saltworks at Minden, in Prussia in June, 1844, itwas exactly 1993 feet, the absolute depth being 2231 feet. The temperature of the water at the bottom was 91 F., which, assuming themean temperature of the air at 4993, gives an augmentation of temperature of 1 for every 54 feet. The absolute depth of the Artesianwell of Grenelle, near Paris, is only 1795 feet. According to the account of the missionary Imbert, the firesprings, Hotsing, of the Chinese, which are sunk to.obtain carbureted hydrogen gas for saltboiling, far exceed our Artesian springs in depth. In the Chinese provinceof Sztitschuan these firesprings are very commonly of the depth ofmore than 2000 feet; indeed, at Tseulieutsing (the place of continualflow) there is a Hotsing which, in the year 1812, was found to be 3197feet deep. (Humboldt, Asie Centrale, t. ii., p.521 and 525. Annalesde l Association de la Propagation de la Foi, 1829, No. 16, p. 369.)The relative depth reached at Mount Massi, in Tuscany, south ofVolterra, amounts, according to Matteuci, to only 1253 feet. The boring at the new saltworks near Minden is probably of about the samerelative depth as the coalmine at Apendale, near Newcastle-underLyme, in Staffordshire, where men work 725 yards below the surfaceof the earth. (Thomas Smith, Miners Guide, 1836,p.160.) Unfortunately, I do not know the exact height of its mouth above the levelof the sea. The relative depth of the Monkwearfhouth mine, nearNewcastle, is only 1496 feet. (Phillips, in the Philos. Mag., vol. v.,1834, p. 446.) That of the Liege coalmine, Espérance, at Seraing,is 1355 feet, according to M. von Dechen, the director; and the oldmine of Marihaye, near ValSt.Lambert, in the valley of the

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Maes,is, according to M. Gernaert, Ingénieur des Mines, 1233 feet in depth.The works of greatest absolute depth that have ever been formedare for the most part situated in such elevated plains or valleys thatthey either do not descend so low as the level of the sea, or at mostreach very little below it. Thus the Eselschacht, at Kuttenberg, in Behemia, a mine which can not now be worked, had the enormous absolute depth of 3778 feet. (Fr. A. Schmidt, Berggesetze der dster Mon.,abth. i., bd.i.,s.xxxii.) Also, at St. Daniel and at Geish, on the Rérerbthel, in the Landgeriché (or provincial district) of Kitzbithl, therewere, in the sixteenth century, excavations of 3107 feet. The plansof the works of the Rérerbthel are still preserved. (See Joseph vonSperges, T'yroler Bergwerksgeschichte, 8.121. Compare, also, Humboldt, Gutachten aber Herantreibung des Meissner Stollens in die Freiberger Erzrevier, printed in Herder, aber den jetz begonnenen Erbstollen, 1838, 8. cxxiv.) We may presume that the knowledge of the extraordinary depth of the Rérerbtihel reached England at an early period,for I find it remarked in Gilbert, de Magnete, that men have penetrated2400 or even 3000 feet into the crust of the Earth. (Exigua videtarterre portio, que unquam hominibus spectanda emerget aut eruitur;cum profundius in ejus viscera, ultra florescentis extremitatis corruptelam, aut propter aquas in magnis fodin, tanquam per venas scaturientesaut propter aeris salubrioris ad vitam o erariorum sustinendam necessaril defectum, aut propter ingentes sumptus ad tantos labores exantJandos multasqu difficultates, ad profundiores terre partes penetrara non possumus; adeo ut quadringentas aut quod rarissime quingentasorgyas in quibusdam metallis descendisse, stupendus omnibus videaturconatus.Gulielmi Gilberti, Colcestrensis, de Magnete Physiologianova. Lond., 1600, p.

of the sea, and zonsequently only about 5,′5;th of theEarths radius. The crystalline masses that have been erupted from active volcanoes, and are generally similar to therocks on the upper surface, have come from depths which,although not accurately determined, must certainly be sixtytimes greater than those to which human labor has been enabled to penetrate. We are able to give in numbers the depthof the shaft where the strata of coal, after penetrating a certain way, rise again at a distance that admits of being accurately defined by measurements. These dips show that thecarboniferous strata, together with the fossil organic remainswhich they contain, must lie, as, for, instance, in Belgium,more than five or six thousand feet[3]

40.)

[3]Basinshaped curved strata, which dip and reappear at measur-

below the present level of the sea, and that the calcareous and the curved strata ofthe Devonian basin penetrate twice that

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abledistances, although their deepest portions are beyond the reach of theminer, afford sensible evidence of the nature of the earths crust at greatdepths below its surface. Testimony of this kind possesses, consequently, a great gergnostic interest. Iam indebted to that excellent geognosist, Von Dechen, for the following obseMations. The depth ofthe coal basin of Liege, at Mont St. Gilles, which I, in conjunction withour friend Von Oeynhausen, have ascertained to be 3890 feet belowthe surface, extends 3464 feet below the surface of the sea, for the absolute height of Mont St. Gilles certainly does not much exceed 400feet; the coal basin of Mons is fully 1865 feet deeper. But all thesedepths are trifling compared with those which are presented by thecoal strata of SaarRevier (Saarbritcken). I have found, after repeatedexaminations, that the lowest coal stratum which is known in the neighboarhood of Duttweiler, near Bettingen, north-east of Saarlouis, must descend tc depths of 20,682 and 22,015 feet (or 36 geographical miles)below.the level of the sea. This result exceeds, hy more than 8000feet, the assumption made in the text regarding the basin of the Devonian strata. This coalfield is therefore sunk as far below the surface of the sea as Chimborazo is elevated above itat a depth at whichthe Earths temperature must be as high as 435 F. Hence, from thehighest pinnacles of the Himalaya to the lowest basins containing thevegetation of an earlier world, there is a vertical distance of abont48 000 feet, or of the 435th part of the Earths radius.

depth. If we compare these subterranean basins with the summits of mountainsthat have hitherto been considered as the most elevated portions of the raised crust of the Earth, we obtain a distance of37,000 feet (about seven miles), that is, about the 34;th ofthe Earths radius. These, therefore, would be the limits ofvertical depth and of the superposition of mineral strata towhich geognostical inquiry could penstrate, even if the general elevation of the upper surface of the earth were equal tothe height of the Dhawalagiri n the Himalaya, or of theSorata in Bolivia. All that lies at a greater depth below thelevel of the sea than the shafts or the basins of which I havespoken, the limits to which mans labors have penetrated, o1than the depths to which the sea has in some few instances-been sounded (Sir James Ross was unable to find bottom with27,600 feet of line), is as much unknown to us as the interiorof the other planets of our solar system. We only know themass of the whole Earth and its mean density by comparingit with the open strata, which alone are accessible to us. Inthe interior of the Earth, where all knowledge of its chemicaland mineralogical character fails, we are again limited to aspure conjecture, as in the remotest bodies that revolve roundthe Sun. We can determine nothing with certainty regard ing the depth at which the geological strata must be supposedto be in state of softening or of liquid fusion, of the cavitiesoccupied by elastic vapor, of the condition of fluids whenheated under an enormous pressure, or of the law of the inerease of density from the upper surface to the center of the Earth.

Chapter 13

Geographical Distribution

The consideration of the increase of heat with the increase of depth toward the interior of our planet, and of the reaction of the interior on the external crust, leads us to the long series of volcanic phenomena. These elastic forces are manifested in earthquakes, eruptions of gas, hot wells, mud volcanoes and lava currents from craters of eruptions, and even in producing alterations in the level of the sea.[1] Large plains and variously indented continents are raised or sunk, lands are separated from seas, and the ocean itself, which is permeated by hot and cold currents, coagulates at both poles, converting water into dense masses of rock, which are either stratified and fixed, or broken up into floating banks. The boundaries of sea and land, of fluids and solids, are thus variously and frequently changed. Plains have undergone oscillatory movements, being alternately elevated and depressed. After the elevation of continents, moun-

[1] [See Daubeney On Volcanoes, 2nd edit., 1848, p. 539, c., on the so-called mud volcanoes, and the reasons advanced in favor of adopting the term salses to designate these phenomena.]– Tr.

tain chains were raised upon long fissures, mostly parallel, and, in that case, probably cotemporaneous; and salt lakes and inland seas, long inhabited by the same creatures, were forcibly separated, the fossil remains of shells and zoophytes still giving evidence of their original connection. Thus, in following phenomena in their mutual dependence, we are led from the consideration of the forces acting in the interior of the Earth to those which cause eruptions on its surface, and by the pressure of elastic vapors give rise to burning streams of lava that flow from open fissures.

The same powers that raised the chains of the Andes and the Himalaya to the regions of perpetual snow have occasioned new compositions and new textures in the rocky masses and have altered the strata which had been previously deposited from fluids impregnated with organic substances. We here trace the series of formations, divided and superposed according to their age, and depending upon the changes of configuration of the surface, the dynamic relations of upheaving forces, and the chemical action of vapors issuing from the fissures.

The form and distribution of continents, that is to say, of that solid portion of the Earth's surface which is suited to the luxurious development of vegetable life, are associated by intimate connection and reciprocal action with the encircling sea, in which organic life is almost entirely limited to the animal world. The liquid element is again covered by the atmosphere, an aerial ocean in which the mountain chains and high plains of the dry land rise like shoals, occasioning a variety of currents and changes of temperature, collecting vapor from the region of clouds, and distributing life and motion by the action of the streams of water which flow from their declivities.

While the geography of plants and animals depends ontheze intricate relations of the distribution of sea and land, thecon-figuration of the surface, and the direction of isothermallines (or zones of equal mean annual heat), we find that thecase is totally different when we consider the human racethe last and noblest subject in a physical description of theglobe. The characteristic differences in races, and their relative numerical distribution over the Earths surface, are conditions aflected not by natural relations alone, but at the sametime and specially, by the progress of civilization, and by moraland intellectual cultivation, on which depends the politicalsuperiority that distinguishes national progress. Some fewraces, clinging, as it were, tv the soil, are supplanted and ruinedby the dangerous vicinity of others more civilized than themselves, until scarce a traceof their existence remains. Otherraces, again, not the strongest in numbers, traverse the liquidelement, and thus become the first to acquire, although late,a geographical knowledge of at least the maritime lands of thewhole surface of our globe, from pole to pole.

I have thus, before we enter on the individual characters of that portion of the delineation of nature which includes the sphere of telluric phenomena, shown generally in what manner the consideration of the form of the Earth and the incessant action of electromagnetism and subterranean heat may enable us to embrace in one view the relations of horizontal expansion and elevation on the Earth's surface, the geognostic type of formations, the domain of the ocean (of the liquid portions of the Earth), the atmosphere with its meteorological processes, the geographical distribution of plants and animals, and, finally, the physical gradations of the human race, which is, exclusively and everywhere, susceptible to intellectual culture. This unity of contemplation presupposes a connection of phenomena according to their internal combination. A mere tabular arrangement of these facts would not fulfill the object I have proposed to myself, and would not satisfy that requirement for cosmical presentation awakened in me by the aspect of nature in my journeyings by sea and land, by the careful study of forms and forces, and by a vivid impression of the unity of nature in the midst of the most varied portions of the Earth. In the rapid advance of all branches of physical science, much that is deficient in this attempt will, perhaps, at no remote period, be corrected and rendered more perfect, for it belongs to the history of the development of knowledge that portions which have long stood isolated become gradually connected and subject to higher laws. I only indicate the empirical path, in which I and many others of similar pursuits with myself are advancing, full of expectation that, as Plato tells us Socrates once desired, Nature may be interpreted by reason alone.[2]

[2]Plato, Phedo, p.97. (Arist., Metaph., p. 985.) Compare Hegel,Philosophie der Geschichte, 1840, s. 16.

Chapter 14

Figure of the Earth

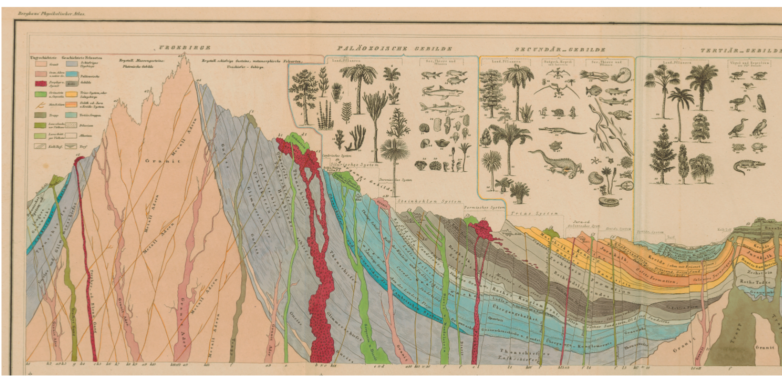

Figure 14.1: Alexander von Humboldt, diagram of a cross-section of the earth's crust, 1841. Public domain.

THE delineation of the principal characteristics of telluric phenomena must begin with the form of our planet and its relations in space. Here, too, we may say that it is not only the mineralogical character of rocks, whether they are crystalline, granular, or densely fossiliferous, but the geometrical form of the Earth itself, which indicates the mode of its origin, and is, in fact, its history. An elliptical spheroid of revolution gives evidence of having once been a soft or fluid mass. Thus, the Earth's compression constitutes one of the most ancient geognostic events, as every attentive reader of the book of nature can easily discern; and an analogous fact is presented in the case of the Moon, the perpetual direction of whose axes toward the Earth, that is to say, the increased accumulation of matter on that half of the Moon which is turned toward us, determines the relations of the periods of rotation and revolution, and is probably cotemporaneous with the earliest epoch in the formative history of this satellite. The mathematical figure of the Earth is that which it would have were its surface covered entirely by water in a state of rest; and it is this assumed form to which all geodesical measurements of degrees refer. This mathematical surface is different from that true physical surface which is affected by all the accidents and inequalities of the solid parts.[1] The whole figure of the Earth is determined when we know the amount of

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[1]Bessel, Aligemeine Betrachtungen aber Gradmessungen nach astronomischgeodatischen Arbeiten, at the conclusion of Bessel and Baeyer, Gradmessung in Ostpreussen, 8. 427. Regarding the accumulation of matter on the side of the Moon turned toward us (a subject noticed in an earlier part of the text), see Laplace, Expos. du Syst. du Monde,p. 308.

the compression at the poles and the equatorial diameter; in order, however, to obtain a perfect representation of its form, it is necessary to have measurements in two directions, perpendicular to one another.

Eleven measurements of degrees (or determinations of the curvature of the Earth's surface in different parts), of which nine only belong to the present century, have made us acquainted with the size of our globe, which Pliny named a point in the immeasurable universe.[2] If these

[2]Plin., ii., 68. Seneca, Nat. Quest., Pref.,c. ii. El mundo es poco (the Earth is small and narrow), writes Columbus from Jamaica to Queen Isabella on the 7th of July, 1503; not because he entertained the philosophic views of the aforesaid Romans, but because it appeared advantageous to him to maintain that the journey from Spain was not long, if, as he observes, we seek the east from the west. Compare my Examen Crit. de V Hist. de la Géogr. du lime Siécle, t.i., p. 83, and t. il., p. 327, where I have shown that the opinion maintained by Delisle, Fréret, and Gosselin, that the excessive differences in the statements regarding the Earth's circumference, found in the writings of the Greeks, are only apparent, and dependent on differ-

measurements do not always accord in the curvatures of different meridians under the same degree of latitude, this very circumstance speaks in favor of the exactness of the instruments and the methods employed, and of the accuracy and the fidelity to nature of these partial results. The conclusion to be drawn from the increase of forces of attraction (in the direction from the equator to the poles) with respect to the figure of a planet is dependent on the distribution of density in its interior. Newton, from theoretical principles, and perhaps likewise prompted by Cassini's discovery, previously to 1666, of the compression of Jupiter,[3] determined,

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ent values being attached to the stadia, was put forward as early as 1495 by Jaime. Ferrer, in a proposition regarding the determination of the line of demarkation of the papal dominions.

[3]Brewster, Life of Sir Isaac Newton, 1831, p. 162. The discovery of the spheroidal form of Jupiter by Cassini had probably directed

in his immortal work, Philosophie Naturalis Principia, that the compression of the Earth, as a homogeneous mass, was g1,th. Actual measurements, made by the aid of new and more perfect analysis, have, however, shown that the compression of the poles of the terrestrial spheroid, when the density of the strata is regarded as increasing toward the center, is very nearly $\frac{1}{300}$th.

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the attention of Newton to the determination of its cause, and, consequently, to the investigation of the true figure of the Earth. Although Cassini did not announce the amount of the compression of Jupiter („th) . till 1691 (Anciens Mémoires de V Acad. des Sciences, t. ti., p. 108), yet we know from Lalande (Astron., 3me éd., t. iii., p. 335) that Moraldi possessed some printed sheets of a Latin work, On the Spots of the Planets, commenced by Cassini, from which it was obvious that he was aware of the compression of Jupiter before the year 1666, and therefore at least twenty-one years before the publication of Newton's Principia.

Figure 14.2: Sir Isaac Newton (25 December 1642 – 20 March 1726/27) was a key figure in the philosophical revolution known as the Enlightenment. His book *Philosophiae Naturalis Principia Mathematica* (1687) established classical mechanics. (Source: Wikipedia). Painting of Newton by Godfrey Kneller is in the public domain.

Three methods have been employed to investigate the curvature of the Earth's surface, viz., measurements of degrees, oscillations of the pendulum, and observations of the inequalities in the Moon's orbit. The first is a direct geometrical and astronomical method, while in the other two we determine from accurately observed movements the amount of the forces which occasion those movements, and from these forces we arrive at the cause from whence they have originated, viz., the compression of our terrestrial spheroid. In this part of my delineation of nature, contrary to my usual practice, I have instanced methods because their accuracy affords a striking illustration of the intimate connection existing among the forms and forces of natural phenomena, and also because their application has given occasion to improvements in the exactness of instruments (as those employed in the measurements of space) in optical and chronological observations; to greater perfection in the fundamental branches of astronomy and mechanics in respect to lunar motion and to the resistance experienced by the oscillations of the pendulum; and to the discovery of new and hitherto untrodden paths of analysis. With the exception of the investigations of the parallax of stars, which led to the discovery of aberration and nutation, the history of science presents no problem in which the object attained—the knowledge of the compression and of the irregular form of our planet—is so far exceeded in importance by the incidental gain which has accrued, through a long and weary course of investigation, in the general furtherance and improvement of the mathematical and astronomical sciences. The comparison of eleven measurements of degrees (in which are included three extra-European, namely, the old Peruvian and two East Indian) gives, according to the most strictly theoretical requirements allowed for by Bessel,[4] a compression of

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[4]According to Bessel's examination of ten measurements of degrees, in which the error discovered by Puissant in the calculation of the French measurements is taken into consideration (Schumacher, Astron. Nachr., 1841, No. 438, s. 116), the semiaxis major of the

$\frac{1}{299}$th. In accordance with this, the polar radius is 10,938 toises (69,944 feet), or about $11\frac{1}{2}$ miles, shorter than the equatorial radius of our terrestrial spheroid. The excess at the equator in consequence of the curvature of the upper surface of the globe

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elliptical naman of revolution to which the irregular figure of the Earth most closely approximates is 3,272,07714 toises, or 20,924,774 feet; the semiaxis minor, 3,261,15983 toises, or 20,854,821 feet; and the amount of compression or eccentricity 555;254; the length of a mean degree of the meridian, 57 013109 toises, or 364,596 feet, with an error of 28403 toises, or 1816 feet, whence the length of a geographical mile is 380723 toises, or 60867 feet. Previous combinations of measurements of degrees varied between ,i,d and 544th; thus Walbeck (De Forma et Magnitudine telluris in demensis arcubus Meridiani definiendis, 1819) gives y57gth Ed. Schmidt (Lehrbuch der Mathem. und Phys. Geographie, 1829, s. 5) gives gyz54, as the mean of seven measures. Respecting the influence of great differences of longitude on the polar compression, see Bibliotheque Universelle, t. xxxiii., p. 181, and t. xxxv., p. 56; likewise Connaissance des Tems, 1829, p.290. From the Itmarinequalities alone, Laplace (Exposition du Syst. du Monde, p.229) found it, by the older tables of Burg, to be gerzth; and subsequently, from the lunar observations of Burckhardt and Bouvard, he fixed it at zoyyth (Mécanique Céleste, t. v., p. 13 and 43).

amounts, consequently, in the direction of gravitation, to somewhat more than 43th times the height of Mont Blanc, or only 2 times the probable height of the summit of the Dhawalagiri, in the Himalaya chain. The lunar inequalities (perturbation in the Moon's latitude and longitude) give, according to the last investigations of Laplace, almost the same result for the ellipticity as the measurements of degrees, viz., z,th. The results yielded by the oscillation of the pendulum give, on the whole, a much greater amount of compression, viz., $\frac{1}{288}$th.[5]

[5]The oscillations of the pendulum give z3'g.zth as the géneral result of Sabine's great expedition (1822 and 1823, from the equator to 80 north latitude); according to Freycinet, 5,15, exclusive of the experiments instituted at the Isle of France, Guam, and Mowi (Mawi); according to Forster, 5,5.5th; according to Duperrey, 5,4„th; and according to Liitke (Partie Nautique, 1836, p. 232), giyth, calculated from eleven stations. On the other hand, Mathieu (Connaiss. des. 'emps, 1816, p. 330) fixed the amount at .,1„d, from observations

made between Formentera and Dunkirk; and Biot, at ,1,th, from observations between Formentera and the island of Unst. Compare Baily, Report on Pendulum Experiments, in the Memoirs of the Royal Astronomical Society, vol. vii., p. 96; also Borenius, in the Bulletin de l'Acad. de St. Pétersbourg, 1843, t.i., p.25. The first proposal to apply the length of the pendulum as a standard of measure, and to establish the third part of the seconds pendulum (then supposed to be every where of equal length) as a pes horarius, or Baegeal waeseufo) that might be recovered at any age and by all nations, is to be found in Huygens's Horologium Oscillatorium, 1673, Prop. 25. A similar wish was afterward publicly expressed, in 1742, on a monument erected at the equator by Bouguer, La Condamine, and Godin. On the beautiful marble tablet which exists, as yet uninjured, in the old Jesuits' College at Quito, I have myself read the inscription, Penduli simplicis equinoctialis untus minuti secundi archetypus, mensure naturalis exemplar, utinam universalis From an observation made by La Condamine, in his Journal du Voyage al Equateur, 1751, p. 163, regarding parts of the inscription that were not filled up, and a slight difference between Bouguer and himself respecting the numbeys, I was led to expect that I should find considerable discrepancies between the marble tablet and the inscription as it had been described in Paris; but, after a careful comparison, I merely found two perfectly unimportant differences ex arcu graduum 34 instead of ex arcu graduum plusquam trium, and the date of 1745 instead of 1742. The latter circumstance is singular, because La Condamine returned to Europe in November, 1744, Bouguer in June of the same year, and Godin had left South America in July, 1744. The most necessary and useful amendment to the numbers on this inscription would

Galileo, who first observed when a boy (having, probably, suffered his thoughts to wander from the service) that the height of the vaulted roof of a church might be measured by the time of the vibration of the chandeliers suspended at different altitudes, could hardly have anticipated that the pendulum would one day be carried from pole to pole, in order to determine the form of the Earth, or, rather, that the unequal density of the strata of the Earth affects the length of the seconds pendulum by means of intricate forces of local attraction, which are, however, almost regular in large tracts of land. These geognostic relations of an instrument intended for the measurement of time, this property

have been the astronomical longitude of Quito. (Humboldt, Recueil d'Odserv. Astron., t. ii., bp. 319354.) Nouet's latitudes, engraved on Egyptian monuments, offer a more recent example of the danger presented by the grave perpetuation of false or careless results.

of the pendulum, by which, like a sounding line, it searches unknown depths, and reveals in volcanic islands,[6] or in the declivity of elevated continental mountain chains,[7] dense masses of basalt and mela-

[6]Respecting the augmented intensity of the attraction of gravitation in volcanic islands (St. Helena, Ualan, Fernando de Noronha, Isle of France, Guam, Mowi, and Galapagos), Rawak (Liitke, p. 240) being an exception, probably in consequence of its proximity to the highland of New Guinea, see Mathieu, in Delambre, Hist. de 1 Astronomie, au 18me Siècle, p. 701.

[7]Numerous observations also show great irregularities in the length of the pendulum in the midst of continents, and which are ascribed to local attractions. (Delambre, Mesure de la Méridienne, t. iii., p. 548; Biot, in the Mém de Académie des Sciences, t. viii., 1829, p. 18 and 23.) In passing over the South of France and Lombardy from west to east, we find the minimum intensity of gravitation at Bordeaux; from thence it increases rapidly as we advance eastward, through Figeac, Clermont-Ferrand, Milan, and Padua; and in the last town we find that the intensity has attained its maximum. The influence of the southern declivities of the Alps is not merely dependent on the general size of their mass, but (much more), in the opinion of Elie de Beaumont (Rech. sur les Révol. de la Surface du Globe, 1830, p. 729), on the rocks of melaphyre and serpentine, which have elevated the chain. On the declivity of Ararat, which with Caucasus may be said to lie in the center of gravity of the old continent

formed by Europe, Asia, and Africa, the very exact pendulum experiments of Fedorow give indications, not of subterranean cavities, but of dense volcanic masses. (Parrot, Reise zum Ararat, bd. ii., s. 143.) In the geodesic operations of Carlini and Plana, in Lombardy, differences ranging from 20 to 478 have been found between direct observations of latitude and the results of these operations. (See the instances of Andrate and Mondovi, and those of Milan and Padua, in the Opérations Geodes. et Astron. pour la Mesure d'un Arc du Parallèle Moyen, t. ii., p. 347; Effemeridi Astron. di Milano, 1842, p. 57.) The latitude of Milan, deduced from that of Berne, according to the French triangulation, is 45 27 52, while, according to direct astronomical observations, it is 45 27 35. As the perturbations extend in the plain of Lombardy to Parma, which is far south of the Po (Plana, Opérat. Geod., t. ii., p. 847), it is probable that there are deflecting causes concealed beneath the soil of the plain itself. Struve has made similar experiments with corresponding results in the most level parts of eastern Europe. (Schumacher, Astron. Nachrichten, 1830, No. 164, s. 399.) Regarding the influence of dense masses supposed to lie at a small depth, equal to the mean height of the Alps, see the analytical expressions given by Hossard and Rozet, in the Comptes Rendus, t. xviii., 1844, p. 292, and compare them with Poisson, Traité de Mécanique (2me éd.), t. i., p. 482. The earliest observations on the influence which different kinds of rocks exercise on the vibration of the pendulum are those of Thomas Young, in the Philos. Transactions for 1819, p. 7096. In drawing conclusions regarding the Earth's curvature from the length of the pendulum, we ought not to overlook the possibility that its crust may have undergone a process of hardening previously to metallic and dense phyre instead of cavities, render it difficult, notwithstanding the admirable simplicity of the method, to arrive at any great result regarding the figure of the Earth from observation of the oscillations of the pendulum. In the astronomical part of the determination of degrees of latitude, mountain chains, or the denser strata of the Earth, likewise exercise, although in a less degree, an unfavorable influence on the measurement. As the form of the Earth exerts a powerful influence on the motions of other cosmical bodies, and especially on that of its own neighboring satellite, a more perfect knowledge of the motion of the latter will enable us reciprocally to draw an inference regarding the figure of the Earth. Thus, as Laplace ably remarks,[8]

basaltic masses having penetrated from great depths, through open clefts, and approached near the surface.

[8]Laplace, Expos. du Syst. du Monde, p. 231.

An astronomer, without leaving his observatory, may, by a comparison of lunar theory with true observations, not only be enabled to determine the form and size of the Earth, but also its distance from the Sun and Moon results that otherwise could only be arrived at by long and arduous expeditions to the most remote parts of both hemispheres.

The compression which may be inferred from lunar inequalities affords an advantage not yielded by individual measurements of degrees or experiments with the pendulum, since it gives a mean amount which is referable to the whole planet. The comparison of the Earth's compression with the velocity of rotation shows further the increase of density from the strata from the surface toward the center, an increase which a comparison of the ratios of the axes of Jupiter and Saturn with their times of rotation likewise shows to exist in these two large planets. Thus, the knowledge of the external form of planetary bodies leads us to draw conclusions regarding their internal character.

The northern and southern hemispheres appear to present nearly the same curvature under equal degrees of latitude, but,as has already been observed, pendulum experiments andmeasurements of degrees yield such different results for individual portions of the Earths surface that no regular figureean be given which would reconcile all the results hithertoobtained by this method. The true figure of the Earth is toa regular figure as the uneven surfaces of water in motion areto the even surface of water at rest.

Chapter 15

Density of the Earth

WHEN the Earth had been measured, it still had to be weighed. The oscillations of the pendulum[1] and the plummet have here likewise served to determine the mean density of the Earth, either in connection with astronomical and geodetic operations, with the view of finding the deflection of the plummet from a vertical line in the vicinity of a mountain, or by a comparison of the length of the pendulum in a plain and on the summit of an elevation, or, finally, by the employment of a torsion balance, which may be considered as a horizontally vibrating pendulum for the measurement of the relative density of neighboring strata. Of these three methods[2] the last is the most certain, since it

[1] La Cailles pendulum measurements at the Cape of Good Hope, which have been calculated with much care by Mathieu (Delambre, Hist. de U Astron. au 18me Siècle, p. 479), give a compression of szy.qth; but, from several comparisons of observations made in equal latitudes in the two hemispheres (New Holland and the Malouines (Falkland Islands), compared with Barcelona, New York, and Dunkirk), there is as yet no reason for supposing that the mean compression of the southern hemisphere is greater than that of the northern. (Biot, in the Mém. del Acad. des Sciences, t. viii., 1829, p. 3941.

[2] The three methods of observation give the following results (1.) by the deflection of the plumbline in the proximity of the Shehallien Mountain (Gaelic, eae) in Perthshire, 4713, as determined by Maskelyne, Hutton, and Playtair (1774-1776 and 1810), according to

a method that had been proposed by Newton; (2.) by pendulum vibrations on mountains, 4837 (Carlinis observations on Mount Cenis compared with Biots observations at Bordeaux, Hffemer. Astron. di Milano, 1824, p. 184); G) by the torsion balance used by Cavendish, with an apparatus originally devised by Mitchell, 548 (according to Huttons revision of the calculation, 532, and according to that of Eduard Schmidt, 552; Lehrbuch der Math. Geographie, bd. i., s. 487); by the torsion balance, according to Reich, 544. In the calculation of these experiments of Professor Reich, which have been made with masterly accuracy, the original mean result was 543 (with a probable error of only 0.00233), a result which, being increased by the Loom by which the Earths centrifugal force diminishes the force of gravity for the latitude of Freiberg (50 55), becomes changed to 544. The employment of cast iron instead of lead has not presented any sensible difference, or none exceeding the limits of errors of observation, hence disclosing no traces of magnetic influences. (Reich, Versuche aber die mittlere Dichtighett der Erde, 1838, s. 60, 62, and 66.) By the assumption of too slight a degree of ellipticity of the Earth, and by the uncertainty of the estimations regarding the density of rocks on its surface, the mean density of the Earth, as deduced from experiments on and near mountains, was found about one sixth smaller than it really is, namely, 4761 (Laplace, Mécan. Céleste, t. v., p. 46), or 4785. (Eduard Schmidt, Lehrb. der Math. Geogr., bd. i., 387 und 418.) On Halleyshypothesis of the Earth hollow sphere (noticed in page 171), which was the germ of Franklins ideas concerning earthquakes, see Philos. Trans. for the year 1693, vol. xvii., p. 563 (On the Structure of the Internal Parts of the Earth, and the concave habited Arch of the Shell). Halley regarded it as more worthy of the Creator is independent of the difficult determination of the density of the mineral masses of which the spherical segment of the mountain consists near which the observations are made. According to the most recent experiments of Reich, the result obtained is 544; that is to say, the mean density of the whole Earth is 544 times greater than that of pure water. As, according to the nature of the mineralogical strata constituting the dry continental part of the Earths surface, the mean density of this portion scarcely amounts to 27, and the density of the dry and liquid surface conjointly to scarcely 16, it follows that the elliptical unequally compressed layers of the interior must greatly increase in density toward the center, either through pressure or ow-

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that the Earth, like a house of several stories, should be inhabited both without and within. For light in the hollow sphere (p. 57) provision might in some manner be contrived.

ing to the heterogeneous nature of the substances. Here again we see that the vertical, as well as the horizontally vibrating pendulum, may justly be termed a geognostical instrument. The results obtained by the employment of an instrument of this kind have led celebrated physicists, according to the difference of the hypothesis from which they started, to adopt entirely opposite views regarding the nature of the interior of the globe. It has been computed at what depths liquid or even gaseous substances would, from the pressure of their own superimposed strata, attain a density exceeding that of platinum or even iridium; and in order that the compression which has been determined within such narrow limits might be brought into harmony with the assumption of simple and infinitely compressible matter, Leslie has ingeniously conceived the nucleus of the world to be a hollow sphere, filled with an assumed imponderable matter, having an enormous force of expansion. These venturesome and arbitrary conjectures have given rise, in wholly unscientific circles, to still more fantastic notions. The hollow sphere has by degrees been peopled with plants and animals, and two small subterranean revolving planets Pluto and Proserpine were imaginatively supposed to shed over it their mild light; as, however, it was further imagined that an everuniform temperature reigned in these internal regions, the air, which was made self-luminous by compression, might well render the planets of this lower world unnecessary. Near the north pole, at 82 latitude, whence the polar light emanates, was an enormous opening, through which a descent might be made into the hollow sphere, and Sir Humphrey Davy and myself were even publicly and frequently invited by Captain Symmes to enter upon this subterranean expedition so powerful is the morbid inclination of men to fill unknown spaces with shapes of wonder, totally unmindful of the counter evidence furnished by well-attested facts and universally acknowledged natural laws. Even the celebrated Halley, at the end of the seventeenth century, hollowed out the Earth in his magnetic speculations Men were invited to believe that a subterranean freely-rotating nucleus occasions by its position the diurnal and annual changes of magnetic declination. It has thus been attempted in our own day, with tedious solemnity, to clothe in a scientific garb the quaintly-devised fiction of the humorous

Holberg.[3]

[3][The work referred to, one of the wittiest productions of the learned Norwegian satirist and dramatist Holberg, was written in Latin, and first appeared under the following title Nicolai Klimit iter subterraneum novam telluris theoriam ac historiam quinte monarchia adhuc nobis incognite exhibens e bibliotheca b. Abelini. Hafnie et Lipsie sumt.Jac. Preuss, 1741. An admirable Danish translation of this learned but severe satire on the institutions, morals, and manners of the inhabitants of the upper Earth, appeared at Copenhagen in 1789, and was entitled Niels Kim's underjordiske reise ved Ludwig Holberg, oversat efter den Latinske original af Jens Baggesen. Holberg, who studied for a time at Oxford, was born at Bergen in 1685, and died in 1754 as Rector of the University of Copenhagen.] – Tr.

Chapter 16

Internal Heat of the Earth

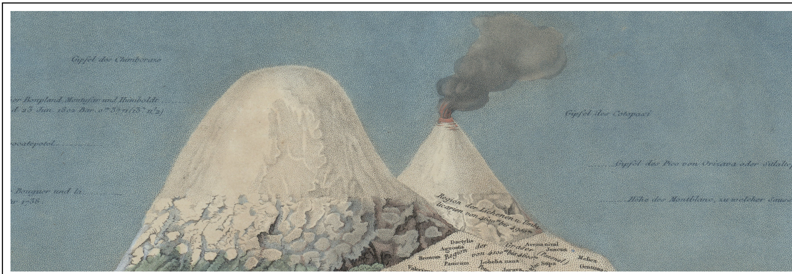

Figure 16.1: Humboldt, *Tableau Physique* (1807). Public domain.

THE figure of the Earth and the amount of solidification (density) which it has acquired are intimately connected with the forces by which it is animated, in so far, at least, as they have been excited or awakened from without, through its planetary position with reference to a luminous central body. Compression, when considered as a consequence of centrifugal force acting on a rotating mass, explains the earlier condition of fluidity of our planet. During the solidification of this fluid, which is commonly conjectured to have been gaseous and primordially heated to a very high temperature, an enormous quantity of latent heat must have been liberated. If the process of solidification began, as Fourier conjectures, by radiation from the cooling surface exposed to the atmosphere, the particles near the center would have continued fluid and hot. As, after long emanation of heat from the center toward the exterior, a stable condition of the temperature of the Earth would at length be established, it has been assumed that with increasing depth the subterranean heat likewise uninterruptedly increases. The heat of the water which flows from deep borings (Artesian wells), direct experiments regarding the temperature of rocks in mines, but, above all, the volcanic activity of the Earth, shown by the flow of molten masses from open fissures, afford unquestionable evidence of this increase for very considerable depths from the upper strata. According to conclusions based certainly upon mere analogies, this increase is probably much greater toward the center.

That which has been learned by an ingenious analytic calculation, expressly perfected for this class of investigations,[1] re-

[1]Here we must notice the admirable analytical labors of Fourier, Biot, Laplace, Poisson, Duhamel, and Lamé. In his Théorie Mathématique de la Chaleur, 1835, p. 3, 428-430, 436, and 521-524 (see, also, De la Rive's abstract in the Bibliotheque Universelle de Genéve), Poisson has developed an hypothesis totally different from Fourier's view (Théorie Analytique de la Chaleur.) He denies the present fluid state of the Earth's center; he believes that in cooling by radiation to the medium surrounding the Earth, the parts which were first solidified sunk, and that by a double descending and ascending current, the great inequality was lessened which would have taken place in a solid body cooling from the surface. It seems more probable to this great geometer that the solidification began in the parts lying nearest to the center. The phenomenon of the increase of heat with the depth does not extend to the whole mass of the Earth, and is merely a consequence of the motion of our planetary system in space, of which some parts are of a very different temperature from others, in consequence of stellar heat (chaleur stellaire). Thus, according to Poisson, the warmth of the water of our Artesian wells is merely that which has penetrated into the Earth from without; and the Earth itself might be regarded as in the same circumstances as a mass of rock conveyed from the equator to the pole in so short a time as not to have entirely cooled. The increase of temperature in such a block would not extend to the central strata. The physical doubts which have reasonably been entertained against

garding the motion of heat in homogeneous metallic spheroids, must be applied with much caution to the actual character of our planet, considering our present imperfect knowledge of the substances of which the Earth is composed, the difference in the capacity of heat and in the conducting power of different superimposed masses, and the chemical changes experienced by solid and liquid masses from any enormous compression. It is with the greatest difficulty that our powers of comprehension can conceive the boundary line which divides the fluid mass of the interior from the hardened mineral masses of the external surface, or the gradual increase of the solid strata, and the condition

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this extraordinary cosmical view (which attributes to the regions of space that which probably is more dependent on the first transition of matter condensing from the gaseous fluid into the solid state) will be found collected in Poggendorf's Annalen, bd. xxxix., s. 93-100.

of semifluidity of the earthy substances, these being conditions to which known laws of hydraulics can only apply under considerable modifications. The Sun and Moon, which cause the sea to ebb and flow, most probably also affect these subterranean depths. We may suppose that the periodic elevations and depressions of the molten mass under the already solidified strata must have caused inequalities in the vaulted surface from the force of pressure. The amount and action of such oscillations must, however, be small; and if the relative position of the attracting cosmical bodies may here also excite spring tides, it is certainly not to these, but to more powerful internal forces, that we must ascribe the movements that shake the Earth's surface. There are groups of phenomena to whose existence it is necessary to draw attention, in order to indicate the universality of the influence of the attraction of the Sun and Moon on the external and internal conditions of the Earth, however little we may be able to determine the quantity of this influence.

According to tolerably accordant experiments in Artesian wells, it has been shown that the heat increases on an average about 1 for every 545 feet. If this increase can be reduced to arithmetical relations, it will follow, as I have already observed[2], that a

[2]See the Introduction. This increase of temperature has been found in the Puits de Grenelle, at Paris, at 583 feet; in the boring at the new saltworks at Minden, almost 536; at Pregny, near Geneva, according to Auguste de la Rive and Marcet, notwithstanding that the mouth of the boring is 1609 feet above the level of the sea, it is also 536 feet. This coincidence between the results of a method first proposed by Arago in the year 1821 (Annuaire du Bureau des Longitudes, 1835, p. 234), for three different mines, of the absolute depths of 1794, 2231, and 725 feet respectively, is remarkable. The two points on the Earth, lying at a small vertical distance from each other, whose annual mean temperatures are most accurately known, are probably at the spot on which the Paris Observatory stands, and the Caves de l'Observatoire beneath it. The mean temperature of the

stratum of granite would be in a state of fusion at a depth of nearly twenty-one geographical miles, or between four and five times the elevation of the highest summit of the Himalaya.

We must distinguish in our globe three

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former is 5195, and of the latter 533, the difference being 198 for 92 feet, or 1 for 5177 feet. (Poisson, Théorie Math. de la Chaleur, p. 415 and 462.) In the course of the last seventeen years, from causes not yet perfectly understood, but probably not connected with the actual temperature of the caves, the thermometer standing there has risen very nearly 094. Although in Artesian wells there are sometimes slight errors from the lateral permeation of water, these errors are less injurious to the accuracy of conclusions than those resulting from currents of cold air, which are almost always present in mines. The general result of Reich's great work on the temperature of the mines in the Saxony mining districts gives a somewhat slower increase of the terrestrial heat, or 1 to 763 feet. (Reich, Beob. uber die Temperatur des Gesteins in verschiedenen Tiefen, 1834, 8. 134.) Phillips, however, found (Pogg., Annalen, bd. xxxiv., s. 191), in a shaft of the coalmine of Monkwearmouth, near Newcastle, in which, as I have already remarked, excavations are going on at a depth of about 1500 feet below the level of the sea, an increase of 1 to 5906 feet, a result almost identical with that found by Arago in the Puits de Grenelle.

different modes for the transmission of heat. The first is periodic, and affects the temperature of the terrestrial strata according as the heat penetrates from above downward or from below upward, being influenced by the different positions of the Sun and the seasons of the year. The second is likewise an effect of the Sun, although extremely slow – a portion of the heat that has penetrated into the equatorial regions moves in the interior of the globe toward the poles, where it escapes into the atmosphere and the remoter regions of space. The third mode of transmission is the slowest of all, and is derived from the secular cooling of the globe, and from the small portion of the primitive heat which is still being disengaged from the surface.

Chapter 17

Mean Temperature Of The Earth

THE periodic changes of temperature which have been occasioned on the Earth's surface by the Sun's position and by meteorological processes are continued in its interior, although to a very inconsiderable

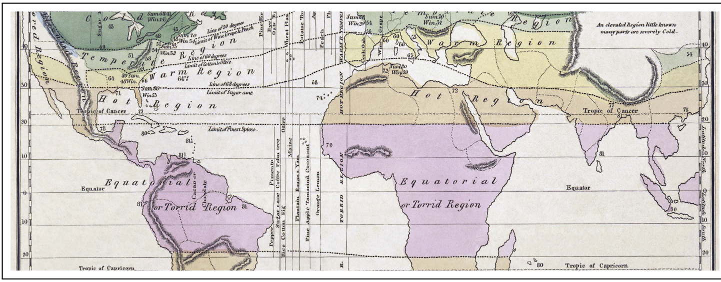

Figure 17.1: W.C. Woodbridge, *Isothermal Chart* (1823). Public domain.

depth. The slow conducting power of the ground diminishes this loss of heat in the winter and is very favorable to deep-rooted trees. Points that lie at very different depths on the same vertical line attain the maximum and minimum of the imparted temperature at very different periods of time. The further they are removed from the surface, the smaller is this difference between the extremes. In the latitudes of our temperate zone (between 48 and 52), the stratum of invariable temperature is at a depth of from 59 to 64 feet, and at half that depth the oscillations of the thermometer, from the influence of the seasons, scarcely amount to half a degree. In tropical climates, this invariable stratum is only one foot below the surface, and this fact has been ingeniously made use of by Boussingault to obtain a convenient, and, as he believes, certain determination of the mean temperature of the air of different places. This mean temperature of the air at a fixed point, or at a group of contiguous points on the surface, is to a certain degree the fundamental element of the climate and agricultural relations of a district; but the mean temperature of the whole surface is very different from that of the globe itself. The questions so often agitated, whether the mean temperature has experienced any considerable differences in the course of centuries, whether the climate of a country has deteriorated, and whether the winters have not become milder and the summers cooler, can only be answered by means of the thermometer; this instrument has, however, scarcely been invented more than two centuries and a half, and its scientific application hardly dates back 120 years. The nature and novelty of the means interpose, therefore, very narrow limits to our investigation regarding the temperature of the air. It is quite otherwise, however, with the solution of the great problem of the internal heat of the whole Earth. As we may judge of uniformity of temperature from the unaltered time of vibration of a pendulum, so we may also learn, from the unaltered rotatory velocity of the Earth, the amount of stability in the mean temperature of our globe. This insight into the relations between the length of the day and the heat of the Earth is the result of one of the most brilliant applications of the knowledge we had long possessed of the movement of the heavens to the thermic condition of our planet. The rotatory velocity of the Earth depends on its volume; and since, by the gradual cooling of the mass by radiation, the axis of rotation would become shorter, the rotatory velocity would necessarily increase, and the length of the day diminish, with a decrease of the temperature. From the comparison of the secular inequalities in the motions of the Moon with the eclipses observed in ancient times, it follows that, since the time of Hipparchus, that is, for full 2000 years, the length of the day has certainly not diminished by the hundredth part of a second. The decrease of the mean heat of the globe during a period of 2000 years has not, therefore, taking the extremest limits, diminished as much as 535th of a degree of Fahrenheit.[1]

This invariability of form presupposes also a great invariability in the distribution of relations of density in the interiorof the globe. The translatory movements, which occasionthe eruptions of our present volcanoes and of ferruginous lava,and the filling up of previously empty fissures and cavitieswith dense masses of stone, are consequently only to be regarded as slight

[1]Laplace, Exp. du Syst. du Monde, p. 229 and 263; MécaniqueCéleste, t. v., p. 18 and 72, It should be remarked that the fractionsooth of a degree of Fahrenheit of the mercurial thermometer, given inthe text as the limit of the stability of the Earths temperature sincthe days of Hipparchus, rests on the assumption that the dilatation ofthe substances of which the Earth is composed is equal to that of glass, that is to say, g.hyath for 1. Regarding this hypathsis, see Aragain the Annuaire for 1834, p. 177190.

superficial phenomena aflecting merely oneportion of the Earths crust, which, from their smallnesswhen compared to the Karths radius, become wholly insignificant.

Chapter 18

Magnetism

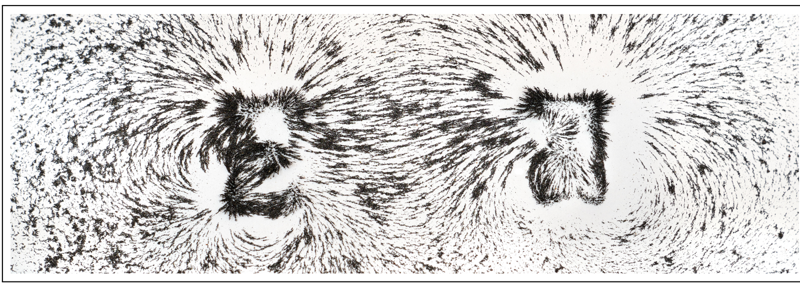

Figure 18.1: W.C. Woodbridge, *Isothermal Chart* (1823). Public domain.

I have described the internal heat of our planet, both with reference to its cause and distribution, almost solely from the results of Fourier's admirable investigations. Poisson doubts the fact of the uninterrupted increase of the Earth's heat from the surface to the center, and is of the opinion that all heat has penetrated from without inward, and that the temperature of the globe depends upon the very high or very low temperature of the regions of space through which the solar system has moved. This hypothesis, imagined by one of the most acute mathematicians of our time, has not satisfied physicists or geologists, or scarcely, indeed, anyone besides its author. But, whatever may be the cause of the internal heat of our planet, and of its limited or unlimited increase in deep strata, it leads us, in this general sketch of nature, through the intimate connection of all primitive phenomena of matter, and through the common bond by which molecular forces are united, into the mysterious domain of magnetism. Changes of temperature call forth magnetic and electric currents. Terrestrial magnetism, whose main character, expressed in the threefold manifestation of its forces, is incessant periodic variability, is ascribed either to the heated mass of the Earth itself,[1] or to those galvanic currents which

[1]William Gilbert, of Colchester, whom Galileo pronounced "great," said "magnus magnes ipse est globus terrestris." He ridicules the magnetic mountains of Frascatori, the great contemporary of Columbus, as being magnetic poles "rejicienda est vulgaris opinio de montibus magneticis, aut rupe aliqua magnetica, aut polo phantastico a polo mundi distante." He assumes the declination of the magnetic needle at any given point on the surface of the Earth to be invariable ("variatio uniuscujusque loci constans est"), and refers the curvatures of the isogonic lines to the configuration of continents and the relative positions of sea basins, which possess a weaker mag-

we consider as electricity in motion, that is, electricity moving in a closed circuit.[2]

The mysterious course of the magnetic needle is equally affected by time and space, by the sun's course, and by changes of place on the Earth's surface. Between the tropics, the hour of the day may be known by the direction of the needle as well as by the oscillations of the barometer. It is affected instantly, but only transiently, by the distant northern light as it shoots from the pole, flashing in beams of colored light across the heavens. When the uniform horary motion of the needle is disturbed by a magnetic storm, the perturbation manifests itself simultaneously, in the strictest sense of the word, over

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netic force than the solid masses rising above the ocean. (Gilbert, de Magnete, ed. 1633, p. 42, 98, 152, and 155.)

[2]Gauss, Allgemeine Theorie des Erdmagnetismus, in the Resultate aus den Beob. des Magnet. Vereins, 1838, s. 41, p. 56.

hundreds and thousands of miles of sea and land, or propagates itself by degrees, in short intervals of time, in every direction over the Earth's surface.[3] In the for-

[3]There are also perturbations which are of a local character, and do not extend themselves far, and are probably less deep-seated. Some years ago I described a rare instance of this kind, in which an extraordinary disturbance was felt in the mines at Freiberg, but was not perceptible at Berlin. (Lettre de M. de Humboldt Son Altesse Royale le Duc de Sussex sur les moyens propres perfectionner la Connaissance du Magnétisme Terrestre, in Becquerel's T'raité Expérimental del Elecsricité, t. vii., p. 442.) Magnetic storms, which were simultaneously felt from Sicily to Upsala, did not extend from Upsala to Alten. (Gauss and Weber, Resultate des Magnet. Vereins, 1839, 128; Lloyd, in the Comptes Rendus de l'Acad. des Sciences, t. xiii., 1843, Sém. 11., p. 725 and 827.) Among the numerous examples that have been recently observed, of perturbations occurring simultaneously and over wide portions of the Earth's surface, and which are collected in Sabine's important work (Observ. on Days of unusual Magnetic Disturbance, 1843), one of the most remarkable is that of the 25th of September, 1841, which was observed at Toronto in Canada, at the Cape of Good Hope, at Prague, and partially in Van Diemen's Land. The English Sunday, on which it is deemed sinful, after midnight on Saturday, to register an observation, and to follow out the great phenomena of creation in their perfect development, interrupted the observations in Van Diemen's Land, where, in consequence of the difference of the longitude, the magnetic storm fell

mer case, the simultaneous manifestation of the storm may serve, within certain limitations, like Jupiter's satellites, fire signals, and well-observed falls of shooting stars, for the geographical determination of degrees of longitude. We here recognize with astonishment that the perturbations of two small magnetic needles, even if suspended at great depths below the surface, can measure the distances apart at which they are placed, teaching us, for instance, how far Kasan is situated east of Göttingen or of the banks of the Seine. There are also districts in the earth where the mariner, who has been enveloped for many days in mist, without seeing either the sun or stars, and deprived of all means of determining the time, may know with certainty, from the variations in the inclination of the mag-

on the Sunday. (Observ., p. xiv., 78, 85, and 87.)

netic needle, whether he is at the north or the south of the port he is desirous of entering.[4]

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[4] I have described, in Lamétherie's Journal de Physique, 1804, t.lix., p. 449, the application (alluded to in the text) of the magnetic inclination to the determination of latitude along a coast running north and south, and which, like that of Chili and Peru, is for a part of the year enveloped in mist (garua). In the locality I have just mentioned, this application is of the greater importance, because, in consequence of the strong current running northward as far as to Cape Parefia, navigators incur a great loss of time if they approach the coast to the north of the haven they are seeking. In the South Sea, from Callao de Lima harbor to Truxillo, which differ from each other in latitude by 3°57′, I have observed a variation of the magnetic inclination amounting to 9 (centesimal division); and from Callao to Guayaquil, which differ in latitude by 9°50′, a variation of 23°95′. (See my Relat. Hist., t. iii., p. 622.) At Guarmey (10°4′ south lat.), Huaura (11°3′ south lat.), and Chancay (11°32′ south lat.), the inclinations are 69°80′, 99°, and 103°5′ of the centesimal division. The determination of position by means of the magnetic inclination has this remarkable feature connected with it, that where the ship's course cuts the isoclinal line almost perpendicularly, it is the only one that is independent of all determination of time, and, consequently, of observations of the sun or stars. It is only lately that I discovered, for the first time, that as early as at the close of the sixteenth century, and consequently hardly twenty years after Robert Norman had invented the inclinatorium, William Gilbert, in his great work

When the needle, by its sudden disturbance in its horary course, indicates the presence of a magnetic storm, we are still unfortunately ignorant whether the seat of the disturbing cause is to be sought in the Earth itself or in the upper regions of the atmosphere. If we regard the Earth as a true magnet, we are obliged, according to the views entertained by Friedrich Gauss (the acute propounder of a general theory of terrestrial magnetism), to ascribe to every portion of the globe measuring

De Magnete, proposed to determine the latitude by the inclination of the magnetic needle. Gilbert (Physiologia Nova de Magnete, lib. v., cap. 8, p. 200) commends the method as applicable aére caliginoso. Edward Wright, in the introduction which he added to his master's great work, describes this proposal as "worth much gold." As he fell into the same error with Gilbert, of presuming that the isoclinal lines coincided with the geographical parallel circles, and that the magnetic and geographical equators were identical, he did not perceive that the proposed method had only a local and very limited application.

one eighth of a cubic meter (or $3\frac{7}{10}$ths of a French cubic foot) in volume, an average amount of magnetism equal to that contained in a magnetic rod of 1 lb. weight.[5] If iron and nickel, and probably, also, cobalt (but not chrome, as has long been believed),[6] are the only substances which become permanently magnetic and retain polarity from a certain coercive force, the phenomena of Arago's magnetism of rotation and of Faraday's induced currents show, on the other hand, that all telluric

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[5]Gauss and Weber, Resultate des Magnet. Vereins, 1838, 31, s. 146.

[6]According to Faraday (London and Edinburgh Philosophical Magazine, 1836, vol. viii., p. 178), pure cobalt is totally devoid of magnetic power. I know, however, that other celebrated chemists (Heinrich Rose and Wéhler) do not admit this as absolutely certain. If out of two carefully purified masses of cobalt totally free from nickel, one appears altogether nonmagnetic (in a state of equilibrium), I think it probable that the other owes its magnetic property to a want of purity; and this opinion coincides with Faraday's view.

substances may possibly be made transitorily magnetic. According to the experiments of the first mentioned of these great physicists, water, ice, glass, and carbon affect the vibrations of the needle entirely in the same manner as mercury in the rotation experiments.[7] Almost all substances show themselves to be, in a certain degree, magnetic when they are conductors, that is to say, when a current of electricity is passing through them.

Although the knowledge of the attracting power of native iron magnets or loadstones appears to be of very ancient date among the nations of the West, there is strong historical evidence in proof of the striking fact that the knowledge of the directive power of a magnetic needle and of

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[7] Arago, in the Annales de Chimie, t. xxxii., p.214; Brewster, J'reatise on Magnetism, 1837, p. 111; Baumgartner, in the Zeitschrift furPhys. und Mathem., bd. ii., s. 419.

its relation to terrestrial magnetism was peculiar to the Chinese, a people living in the easternmost portions of Asia. More than a thousand years before our era, in the obscure age of Codrus, and about the time of the return of the Heraclidae to the Peloponnesus, the Chinese had already magnetic carriages, on which the movable arm of the figure of a man continually pointed to the south, as a guide by which to find the way across the boundless grass plains of Tartary; nay, even in the third century of our era, therefore at least 700 years before the use of the mariners compass in European seas, Chinese vessels navigated the Indian Ocean[8] under the direction of magnetic needles pointing to the south. I have shown, in another work, what advan-

[8]Humboldt, Examen Critique de l'Hist. de la Géographie, t. iii., p. 36.

tages this means of topographical direction, and the early knowledge and application of the magnetic needle gave the Chinese geographers over the Greeks and Romans, to whom, for instance, even the true direction of the Apennines and Pyrenees always remained unknown.[9]

The magnetic power of our globe is manifested on the terrestrial surface in three classes of phenomena, one of which exhibits itself in the varying intensity of the force, and the two others in the varying direction of the inclination, and in the

[9] Asiatic Researches, t. i., Introduction, p. xxxviii-xlii. The Western nations, the Greeks and the Romans, knew that magnetism could be communicated to iron, and that the metal would retain it for a length of time. (Sola hec materia ferri vires, a magnete lapide accipit, retinezque longo tempore. Plin., xxxiv.,14.) The great discovery of the terrestrial directive force depended, therefore, alone on this, that no one in the West had happened to observe an elongated fragment of magnetic iron stone, or a magnetic iron rod, floating, by the aid of a piece of wood, in water, or suspended in the air by a thread, in such a position as to admit of free motion.

horizontal deviation from the terrestrial meridian of that spot. Their combined action may therefore be graphically represented by three systems of lines, the isodynamic, isoclinic, and isogonic (or those of equal force, equal inclination, and equal declination). The distances apart, and the relative positions of these moving, oscillating, and advancing curves, do not always remain the same. The total deviation (variation or declination of the magnetic needle) has not at all changed, or, at any rate, not in any appreciable degree, during a whole century, at any particular point on the Earth's surface,[10] as, for instance, the

[10] A very slow secular progression, or a local invariability of the magnetic declination, prevents the confusion which might arise from terrestrial influences in the boundaries of land, when, with an utter disregard for the correction of declination, estates are, after long intervals, measured by the mere application of the compass. The whole mass of West Indian property, says Sir John Herschel, has been saved from the bottomless pit of endless memories by the in-

western part of the Antilles, or Spitzbergen. In like manner, we observe that the isogonic curves, when they pass in their secular motion from the surface of the sea to a continent or an island of considerable extent, continue for a long time in the same position, and become inflected as they advance.

These gradual changes in the forms assumed by the lines in their translatory motions, and which so unequally modify the amount of eastern and western declination, in the course of time render it difficult to trace the transitions and analogies of forms in the graphic representations be-

variability of the magnetic declination in Jamaica and the surrounding Archipelago during the whole of the last century, all surveys of property there having been conducted solely by the compass. See Robertson, in the Philosophical Transactions for 1806, Part ii., p. 348, On the Permanency of the Compass in Jamaica since 1660. In the mother country (England) the magnetic declination has varied by fully 14 during that period.

longing to different centuries. Each branch of a curve has its history, but this history does not reach further back among the nations of the West than the memorable epoch of the 13th of September, 1492, when the rediscoverer of the New World found a line of no variation 3 west of the meridian of the island of Flores, one of the Azores.[11] The whole of Europe, ex-

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[11] I have elsewhere shown that, from the documents which have come down to us regarding the voyages of Columbus, we can, with much certainty, fix upon three places tm the Atlantic line of no declination for the 13th of September, 1492, the 2ist of May, 1496, and the 16th of August, 1498. The Atlantic line of no declination at that period ran from northeast to southwest. It then touched the foutk American continent a little east of Cape Codera, while it is now observed to reach that continent on the northern coast of the Brezik (Humboldt, Ezamen Critique de l Hist. de la Géogr., t. iii., p. 44 - 48 From Gilberts Phystologia Nova de Magnete, we see plainly (and the fact is very remarkable) that in 1600 the declination was still null in the region of the Azores, just as it had been in the time of Columbus (lib. 4, cap. 1). I believe that in my Examen Critique (t. iii., p. 54) I have proved from documents that the celebrated line of demarkation by which Pope Alexander VI. divided the Western hemisphere be-

cepting a small part of Russia, has now a western declination, while at the close of the seventeenth century the needle first pointed due north, in London in 1657, and in Paris in 1669, there being thus a difference of twelve years, notwithstanding the small distance between these two places. In Eastern Russia, to the east of the mouth of the Volga, of Saratow, Nischni Nowgorod, and Archangel, the easterly declination of Asia is advancing toward us. T'wo admirable observers, Hansteen and Adolphus Erman, have made us acquainted with the remarkable double cur-

tween Portugal and Spain was not drawn through the most western point of the Azores, because Columbus wished to convert a physical into a political division. He attached great importance to the zone (raya) sci) which the compass shows no variation, where air and ocean, the latter covered with pastures of seaweed, exhibit a peculiar constitution, where cooling winds begin to blow, and where as erroneous observations of the polar star led him to imagine the form (sphericity) of the Earth is no longer the same.

vature of the lines of declination in the vast region of Northern Asia; these being concave toward the pole between Obdorsk, on the Oby, and Turuchansk, and convex between the Lake of Baikal and the Gulf of Ochotsk. In this portion of the earth, in northern Asia, between the mountains of Werchojansk, Jakutsk, and the northern Korea, the isogonic lines form a remarkable closed system. This oval configuration[12] recurs regularly, and over a great

[12]To determine whether the two oval systems of isogonic lines, so singularly included each within itself, will continue to advance for centuries in the same enclosed form, or will unfold and expand themselves, is a question of the highest interest in the problem of the physical causes of terrestrial magnetism. In the Eastern Asiatic nodes the declination increases from without inward, while in the node or oval system of the South Sea the opposite holds good; in fact, at the present time, in the whole South Sea to the east of the meridian of Kamtschatka, there is no line where the declination is null, or, indeed, in which it is less than 2 (Erman, in Pogg., Annal., bd. xxxi., 129). Yet Cornelius Schouten, on Easter Sunday, 1616; appears to have found the declination null somewhere to the southeast

extent of the South Sea, almost as far as the meridian of Pitcairn and the group of the Marquesas Islands, between 20 north and 45 south lat. One would almost be inclined to regard this singular configuration of closed, almost concentric, lines of declination as the effect of a local character of that portion of the globe; but if, in the course of centuries, these apparently isolated systems should also advance, we must suppose, as in the case of all great natural forces, that the phenomenon arises from some general cause.

The horary variations of the declination, which, although dependent upon true time, are apparently governed by the

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of Nukahiva, in 15 south lat. and 132 west long., and consequently in the middle of the present closed isogonal system. (Hansteen, Magnet. der Erde, 1819, 28.) It must not be forgotten, in the midst of all these considerations, that we can only follow the direction of the magnetic lines in their progress as they are projected upon the surface of the Earth.

Sun, as long as it remains above the horizon, diminish in angular value with the magnetic latitude of place. Near the equator, for instance, in the island of Rawak, they scarcely amount to three or four minutes, while they are from thirteen to fourteen minutes in the middle of Europe. As in the whole northern hemisphere the north point of the needle moves from east to west on an average from 8:00 AM until 1:00 PM, while in the southern hemisphere the same north point moves from west to east.[13] Attention has recently been drawn, with much justice, to the fact that there must be a region of the Earth between the terrestrial and the magnetic equator where no horary deviations in the declination are to be observed. This fourth curve, which might be called the *curve of no motion*, or,

[13] Arago, in the Annuaire, 1836, p. 284, and 1840, p. 330-338.

rather, *the line of no variation of horary declination*, has not yet been discovered.

The term *magnetic poles* has been applied to those points of the Earth's surface where the horizontal power disappears, and more importance has been attached to these points than properly appertains to them;[14] and in like manner, the curve, where the inclination of the needle is null, has been termed the *magnetic equator*. The position of this line and its secular change of configuration have been made an object of careful investigation in modern times. According to the admirable work of Duperrey,[15] who crossed the magnetic equator six times between 1822 and

[14]Gauss, Allg. Theorie des Erdmagnet., 31.

[15]Duperrey, De la Configuration de Equateur Magnétique, in the Annales de Chimie, t. xlv., p. 371 and 379. (See, also, Morlet, in the Mémoires présentés par divers Savans a l Acat. Roy. des Sciences, t. iii. p 132.)

1825, the nodes of the two equators, that is to say, the two points at which the line without inclination intersects the terrestrial equator, and consequently passes from one hemisphere into the other, are so unequally placed, that in 1825 the node near the island of St. Thomas, on the western coast of Africa, was $188\frac{1}{2}^{\circ}$ distant from the node in the South Sea, close to the little islands of Gilbert, nearly in the meridian of the Viti group. In the beginning of the present century, at an elevation of 11,936 feet above the level of the sea, I made an astronomical determination of the point (7°1′ south lat., 48°40′ west long. from Paris), where, in the interior of the New Continent, the chain of the Andes is intersected by the magnetic equator between Quito and Lima. To the west of this point, the magnetic equator continues to traverse the South Sea in the southern hemisphere, at the same time slowly drawing near the terrestrial equator. It first passes into the northern hemisphere a little before it approaches the Indian Archipelago, just touches the southern points of Asia, and enters the African continent to the west of Socotora, almost in the Straits of BabelMandeb, where it is most distant from the terrestrial equator. After intersecting the unknown regions of the interior of Africa in a southwest direction, the magnetic equator reenters the south tropical zone in the Gulf of Guinea, and retreats so far from the terrestrial equator that it touches the Brazilian coast near Os Ilheos, north of Porto Seguro, in 15 south lat. From thence to the elevated plateaux of the Cordilleras, between the silver mines of Micuipampa and Caxamarca, the ancient seat of the Incas, where I observed the inclination, the line traverses the whole of South America, which in these latitudes is as much a magnetic *terra incognita* as the interior of Africa.

The recent observations of Sabine[16] have shown that the node near the island of St. Thomas has moved 4 from east to west between 1825 and 1837. It would be extremely important to know whether the opposite pole, near the Gilbert Islands, in the South Sea, has approached the meridian of the Carolinas in a westerly direction. These general remarks will be sufficient to connect the different systems of isoclinic non-parallel lines with the great phenomenon of equilibrium which is manifested in the magnetic equator. It

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[16]See the remarkable chart of isoclinic lines in the Atlantic Ocean for the years 1825 and 1837, in Sabine's Contributions to Terrestrial Magnetism, 1840, p. 134.

is no small advantage, in the exposition of the laws of terrestrial magnetism, that the magnetic equator (whose oscillatory change of form and whose nodal motion exercise an influence on the inclination of the needle in the remotest districts of the world, in consequence of the altered magnetic latitudes)[17] should traverse the ocean throughout its whole course, excepting about one fifth, and consequently be made so much more accessible, owing to the remarkable relations in space between the sea and land, and to the means of which we are now possessed for determining with much exactness both the declination and the inclination at sea.

We have described the distribution of magnetism on the surface of our planet

[17]Humboldt, Über die seculäre Veränderung der Magnetischen Inclination (On the secular Change in the Magnetic Inclination), in Pogg. Annal., bd. xv., s. 322.

according to the two forms of declination and inclination; it now, therefore, remains for us to speak of the intensity of the force which is graphically expressed by isodynamic curves (or lines of equal intensity). The investigation and measurement of this force by the oscillations of a vertical or horizontal needle have only excited a general and lively interest in its telluric relations since the beginning of the nineteenth century. The application of delicate optical and chronometrical instruments has rendered the measurement of this horizontal power susceptible of a degree of accuracy far surpassing that attained in any other magnetic determinations. The isogonic lines are the more important in their immediate application to navigation, while we find from the most recent views that isodynamic lines, especially those which indicate the horizontal force, are the most valuable elements in the theory of terrestrial magnetism.[18] One of the earliest facts yielded by observation is that the intensity of the total force increases from the equator toward the pole.[19]

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[18]Gauss, Resultate der Beob. des Magn. Vereins, 1838, 21; Sabine, Report on the Variations of the Magnetic Intensity, p. 63.

[19]The following is the history of the discovery of the law that the intensity of the force increases (in general) with the magnetic latitude. When I was anxious to attach myself, in 1798, to the expedition of Captain Baudin, who intended to circumnavigate the globe, I was requested by Borda, who took a warm interest in the success of my project, to examine the oscillations of a vertical needle in the magnetic meridian in different latitudes in each hemisphere, in order to determine whether the intensity of the force was the same or whether it varied in different places. During my travels in the tropical regions of America, I paid much attention to this subject. I observed that the same needle, which in the space of ten minutes made 245 oscillations in Paris, 246 in the Havana, and 242 in Mexico, performed only 216 oscillations in the same period at St. Carlos da Rio Negro (1° 53′ north lat. and 80° 49′ west long. from Paris), on the magnetic equator, i.e., the line in which the inclination is 0°; in Peru (7° 1′ south lat. and 80° 40′ west long. from Paris) only 211; while at Lima (12° 2′ south lat.) the number rose to 219.

I found, in the years intervening between 1799 and 1803, that the whole force, if we assume it at 10000 on the magnetic equator in the Peruvian Andes, between Micuipampa and Caxamarca, may be expressed at Paris by 13482, in Mexico by 13155, in San Carlos del Rio Negro by 10480, and in Lima by 10773. When I developed this law of the variable intensity of terrestrial magnetic force and supported it by the numerical value of observations instituted in 104 different places, in a Memoir read before the Paris Institute on the 26th Frimaire, An. XIII. (of which the mathematical portion was contributed by M. Biot), the facts were regarded as altogether new. It was only after the reading of the paper, as Biot expressly states (Lamétherie, Journal de Physique, t. lix., p. 446, note 2), and as I have repeated in the Relation Historique, t. i., p. 262, note 1, that M. de Rossel communicated to Biot his oscillation experiments made six years earlier (between 1791 and 1794) in Van Diemens Land, in Java, and in Amboyna. These experiments gave evidence of the same law of decreasing force in the Indian Archipelago. It must, I think, be supposed that this excellent man, when he wrote his work, was not aware of the regularity of the augmentation and diminution of the intensity, as before the reading of my paper he never mentioned this (certainly not unimportant) physical law to any of our mutual friends, La Place, Delambre, Prony, or Biot. It was not till 1808, four years after my return from America, that the observations made by M. de Rossel were published in the Voyage de l'Entrecasteauz, t. ii., p. 287, 291, 321, 480, and 644. Up to the present day, it is still usual, in all the tables of magnetic intensity which have been published in Germany (Hansteen, Magnet. der Erde, 1819, s. 71; Gauss, Beob. des Magnet. Vereins, 1838, s. 36-39; Erman, Physikal. Beob., 1841, s. 529-579), in England (Sabine, Report on Magnet. Intensity, 1838, p. 43-62; Contributions to Terrestrial Magnetism, 1843), and in France (Becquerel, Traité de Electr. et de Magnét., t. vii., p. 354-367), to reduce the oscillations observed in any part of the Earth to the standard of force which I found on the magnetic equator in Northern Peru, so that, according to the unit thus arbitrarily assumed, the intensity of the magnetic force at Paris is put down as 1348. The observations made by Lamanon in the unfortunate expedition of La Perouse, during the stay at Teneriffe (1785), and on the voyage to Macao (1787), are still older than those of Admiral Rossel. They were sent to the Academy of Sciences, and it is known that they were in the papers of Condorcet in the July of 1787 (Becquerel, t. vii., p. 320); but, notwithstanding the most careful search, they are not now to be found. From a copy of a very important letter of Lamanon, now in the possession of Captain Duperrey, which was addressed to the then perpetual secretary of the Academy of Sciences but was omitted in the narrative of the Voyage de La Perouse, it is stated that the attractive force of the magnet is less in the tropics than when we approach the poles, and that the magnetic intensity deduced from the number of oscillations of the needle of the inclination compass varies and increases with the latitude. If the Academicians, while they continued to expect the return of the unfortunate La Perouse, had felt themselves justified, in the course of 1787, in publishing a truth which had been independently discovered by no less than three different travelers, the theory of terrestrial magnetism would have been extended by the knowledge of a new class of observations, dating eighteen years earlier than they now do. This simple statement of facts may probably justify the observations

The knowledge which we possess of the quantity of this increase, and of all the

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contained in the third volume of my Relation Historique (p. 615). The observations on the variation of terrestrial magnetism, to which I have devoted myself for thirty-two years, by means of instruments which admit of comparison with one another, in America, Europe, and Asia, embrace an area extending over 188 degrees of longitude, from the frontier of Chinese Dzoungarie to the west of the South Sea bathing the coasts of Mexico and Peru, and reaching from 60° north lat. to 12° south lat. I regard the discovery of the law of the decrement of magnetic force from the pole to the equator as the most important result of my American voyage. Although not absolutely certain, it is very probable that Condorcet read Lamanon's letter of July 1787 at a meeting of the Paris Academy of Sciences; and such a simple reading I regard as a sufficient act of publication. (Annuaire du Bureau des Longitudes, 1842, p. 463.) The first recognition of the law belongs, therefore, beyond all question, to the companion of La Perouse; but, long disregarded or forgotten, the knowledge of the law that the intensity of the magnetic force of the Earth varied with the latitude did not, I conceive, acquire an existence in science until the publication of my observations from 1798 to 1804. The object and the length of this note will not be indifferent to those who are familiar with the recent history of magnetism and the doubts that have been started in connection with it, and who, from their own experience, are aware that we are apt to attach some value to that which has cost us the uninterrupted labor of five years, under the pressure of a tropical climate, and of perilous mountain expeditions.

numerical relations of the law of intensity affecting the whole Earth, is especially due, since 1819, to the unwearied activity of Edward Sabine, who, after having observed the oscillations of the same needles at the American north pole, in Greenland, at Spitzbergen, and on the coasts of Guinea and Brazil, has continued to collect and arrange all the facts capable of explaining the direction of the isodynamic lines. J have myself given the first sketch of an isodynamic system in zones for a small part of South America. These lines are not parallel to lines of equal inclination (isoclinic lines), and the intensity of the force is not at its minimum at the magnetic equator, as has been supposed, nor is it even equal at all parts of it. If we compare Ermans observations in the southern part of the Atlantic Ocean, where a faint zone (0706) extends from Angola over the island of St. Helena to the Brazilian coast, with the most recent investigations of the celebrated navigator James Clark Ross, we shall find that on the surface of our planet the force increases almost in the relation of 1 to 3 toward the magnetic south pole, where Victoria Land extends from Cape Crozier toward the volcano Erebus, which has been raised to an elevation of 12,600 feet above the ice.[20] If

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[20]From the observations hitherto collected, it appears that the maximum of intensity for the whole surface of the Earth is 2052, and the minimum 0.706. Both phenomena occur in the southern hemisphere; the former in 73°47′ S, lat., and 169°30′ E. long. from Paris, near Mount Crozier, west northwest of the south magnetic pole, at a place where Captain James Ross found the inclination of the needle to be 87°11′ (Sabine, Contributions to Terrestrial Magnetism, 1843, No. 5, p.231); the latter, observed by Erman, at 19°59′S. lat., and 37°24′ W. long. from Paris, 320 miles eastward from the Brazilian coast of Espiritu Santo (Erman, Phys. Beob., 1841, s. 570), at a point where the inclination is only 79°55′. The actual ratio of the two intensities is therefore as 1 to 2906. It was long believed that the greatest intensity of the magnetic force was only two and a half times as great as the weakest exhibited on the Earth's surface. (Sabine, Report on

the intensity near the magnetic south pole be expressed by 2052 (the unit still employed being the intensity which I discovered on the magnetic equator in Northern Peru), Sabine found it was only 1624 at the magnetic north pole near Melville Island (74°27′ north lat.), while it is 1803 at New York, in the United States, which has almost the same latitude as Naples.

The brilliant discoveries of Cirsted, Arago, and Faradayhave established a more intimate connection between the electric tension of the atmosphere and the magnetic tension of ourterrestrial globe. While Cirsted has discovered that electricity excites magnetism in the neighborhood of the conducting body, Faradays experiments have elicited electric currentsfrom the liberated magnetism. Magnetism is

Magnetic Intensity, p. 82.)

one of the manifold forms under which electricity reveals itself. The ancientvague presentiment of the identity of electric and magneticattraction has been verified in our own times. When electrum (amber), says Pliny, in the spirit of the Ionic naturalphilosophy of Thales,[21] is *animated* by friction and heat, itwill attract bark and dry leaves precisely as the loadstone attracts iron. The same words may be found in the literatureef an Asiatic nation, and occur in a eulogium on the loadstone by the Chinese physicist Kuopho.[22] I observed with

[21]Of amber (succinum, glessum) Pliny observes (xxxvii., 3), Genera ejus plura. Attritu digitorum accepta caloris anima trahunt in sepaleas ac folia arida que levia sunt, ac ut magnes lapis ferri ramentaquoque. (Plato,in Timao, p. 80. Martin, Etude sur le Timée, t. ii.,p. 343346. Strabo, xv., p. 703, Casaub.; Clemens Alex., Strom., ii.,p 370, where, singularly enough, a difference is made between 1dcotx.ov and 76 AeKtpov.) When Thales, in Aristot., de Anima, 1, 2,and Hippias, in Diog. Laert., i., 24, describe the magnet and amber aspossessing a soul, they refer only to a moving principle.

[22]"The magnet attracts iron as amber does the smallest grain of

astonishment, on the woody banks of the Orinoco, in the sportsof the natives, that the excitement of electricity by frictionwas known to these savage races, who occupy the very lowestplace in the scale of humanity. Children may be seen to rubthe dry, flat, and shining sceds or husks of a trailing plantprobably a Wegretia) until they are able to attract threadsof cotton and pieces of bamboo cane. That which thus delights the naked coppercolored Indian is calculated to awakenin our minds a deep and earnest impression. What a chasmdivides the electric pastime of these savages from the discovery of a metallic

mustard seed. It is like a breath of wind which mysteriously penetratesthrough both, and communicates itself with the rapidity of an arrow." These are the words of Kuopho, a Chinese panegyrist on the magnet,who wrote in the begianing of the fourth century. (Klaproth, Lettre aM. A. de Humboldt, su U Invention de la Boussole, 1834, p. 125.)

conductor discharging its electric shocks, or apilcomposed of many chemicallydecomposing substances, ora lightengendering magnetic apparatus In such a chasmlie buried thousands of years that compose the history of theintellectual development of mankind!

The incessant change or oscillatory motion which we discover in all magnetic phenomena, whether in those of the inclination, declination, and intensity of these forces, according to the hours of the day and the night, and the seasons and the course of the whole year, leads us to conjecture the existence of very various and partial systems of electric currents on the surface of the Earth. Are these currents, as in Seebeck's experiments, thermomagnetic, and excited directly from unequal distribution of heat or should we not rather regard them as induced by the position of the Sun and by solar heat?[23] Have the rotation of the planets, and the different degrees of velocity which the individual zones acquire, according to their respective distances from the equator, any influence on the distribution of magnetism? Must we seek the seat of these currents, that is to say, of the disturbed electricity, in the atmosphere, in the regions of planetary space, or in the polarity of the Sun and Moon? Galileo, in his celebrated Dialogo, was inclined to ascribe the parallel direction of the axis of the Earth

[23]The phenomena of periodical variations depend manifestly on the action of solar heat, operating probably through the medium of thermoelectric currents induced on the Earth's surface. Beyond this rude guess, however, nothing is as yet known of their physical cause. It is even still a matter of speculation whether the solar influence be a principal or a subordinate cause in the phenomena of terrestrial magnetism. (Observations to be made in the Antarctic Expedition, 1840, p. 35.)

to a magnetic point of attraction seated in universal space.

If we represent to ourselves the interior of the Earth as fused and undergoing an enormous pressure, and at a degree of temperature the amount of which we are unable to assign, we must renounce all idea of a magnetic nucleus of the Earth. All magnetism is certainly not lost until we arrive at a white heat,[24] and it is manifested when iron is at a dark red heat, however different, therefore, the modifications may be which are excited in substances in their molecular state, and in the coercive force depending upon that condition in experiments of this nature, there will still re-

[24]Barlow, in the Philos. Trans. for 1822, Pt. i., p. 117; Sir David Brewster, Treatise on Magnetism, p. 129. Long before the times of Gilbert and Hooke, it was taught in the Chinese work Ovwthsatsouthat heat diminished the directive force of the magnetic needle. (Klaproth, Lettre à M. A. de Humboldt, sur l'Invention de la Boussole, p. 95.)

main a considerable thickness of the terrestrial stratum, which might be assumed to be the seat of magnetic currents. The old explanation of the horary variations of declination by the progressive warming of the Earth in the apparent revolution of the Sun from east to west must be limited to the uppermost surface, since thermometers sunk into the Earth, which are now being accurately observed at so many different places, show how slowly the solar heat penetrates even to the inconsiderable depth of a few feet. Moreover, the thermic condition of the surface of water, by which two thirds of our planet is covered, is not favorable to such modes of explanation, when we have reference to an immediate action and not to an effect of induction in the aerial and aqueous investment of our terrestrial globe.

In the present condition of our knowledge, it is impossible to afford a satisfactory reply to all questions regarding the ultimate physical causes of these phenomena. It is only with reference to that which presents itself in the triple manifestations of the terrestrial force, as a measurable relation of space and time, and as a stable element in the midst of change, that science has recently made such brilliant advances by the aid of the determination of mean numerical values. From Toronto in Upper Canada to the Cape of Good Hope and Van Diemens Land, from Paris to Pekin, the Earth has been covered, since 1828, with magnetic observatories,[25] in which

[25] As the first demand for the establishment of these observatories (a network of stations, provided with similar instruments) proceeded from me, I did not dare to cherish the hope that I should live long enough to see the time when both hemispheres should be uniformly covered with magnetic houses under the associated activity

of able physicists and astronomers. This has, however, been accomplished, and chiefly through the liberal and continued support of the Russian and British governments.

In the years 1806 and 1807, I and my friend and fellow laborer, Herr Oltmanns, while at Berlin, observed the movements of the needle, especially at the times of the solstices and equinoxes, from hour to hour, and often from half hour to half hour, for five or six days and nights uninterrupted. I had persuaded myself that continuous and uninterrupted observations of several days and nights (observatio perpetua) were preferable to the single observations of many months. The apparatus, a Pronys magnetic telescope, suspended in a glass case by a thread devoid of torsion, allowed angles of seven or eight seconds to be read off on a finely divided scale, placed at a proper distance, and lighted at night by lamps. Magnetic perturbations (storms), which occasionally recurred at the same hour on several successive nights, led me even then to desire extremely that similar apparatus should be used to the east and west of Berlin, in order to distinguish general terrestrial phenomena from those which are mere local disturbances, depending on the inequality of heat in different parts of the Earth, or on the cloudiness of the atmosphere. My departure to Paris, and the long period of political disturbance that involved the whole of the west of Europe, prevented my wish from being then accomplished. (Ersted's great discovery (1820) of the intimate connection between electricity and magnetism again excited a general interest (which had long flagged) in the periodical variations of the electromagnetio tension of the Earth. Arago, who many years previously had commenced in the Observatory at Paris, with a new and excellent declination instrument by Gambey, the longest uninterrupted series of horary observations which we possess in Europe, showed, by a comparison with simultaneous observations of perturbation made at Kasan, what advantages might be obtained from corresponding measurements of declination. When I returned to Berlin, after an eighteen years residence in France, I had a small magnetic house erected in the autumn of 1828, not only with the view of carrying on the work commenced in 1806, but more with the object that simultaneous observations at hours previously determined might be made at Berlin, Paris, and Freiburg, at a depth of 35 fathoms below the surface. The simultaneous occurrence of the perturbations, and the parallelism of the movements for October and December, 1829, were then graphically represented. (Pogg., Annalen, bd. xix., 8. 357, taf. iiii.) An expedition into Northern Asia, undertaken in 1829, by command of the Emperor of Russia, soon gave me an opportunity of working out my plan on a larger scale. This plan was laid before a select committee of one of the Imperial Academies of Science, and, under the protection of the Director of the Mining Department, Count von Cancrin, and the excellent ma aepaone of Professor Kupffer, magnetic stations were appointed over the whole of Northern Asia, from Nicolajeff, in the line through Catharinenburg, Barnaul, and Nertschinsk, to Pekin.

The year 1832 (Göttinger gelehrte Anzeigen, st. 206) is distinguished as the great epoch in which the profound author of a general theory of terrestrial magnetism, Friedrich Gauss, erected apparatus, constructed on a new principle, in the Göttingen Observatory. The magnetic observatory was finished in 1834, and in the same year Gauss distributed new instruments, with instructions for their use, in which the celebrated physicist, Wilhelm Weber, took extreme interest, over a large portion of Germany and Sweden, and the whole of Italy. (Resultate der Beob. des Magnetischen Vereins im Jahr 1338, 8. 135, and Poggend., Annalen, bd. xxxiii., s. 426.) In the magnetic association that was now formed with Göttingen for its center, simultaneous observations have been undertaken four times a year since 1836, and continued uninterruptedly for twenty-four hours. The periods, however, do not coincide with those of the equinoxes and solstices, which I had proposed and followed out in 1830. Up to this period, Great Britain, in possession of the most extensive commerce and the largest navy in the world, had taken no part in the movement which since 1828 had begun to yield important results for the more fixed groundwork of terrestrial magnetism. I had the good fortune, by a public appeal from Berlin, which I sent in April, 1836, to the Duke of Sussex, at that time President of the Royal Society (Lettre de M. de Humboldt a S.A.R. le Duc de Sussex, sur les moyens propres à perfectionner la connaissance du magnétisme terrestre par l'établissement des stations magnétiques et d'observations correspondantes), to excite a friendly interest in the undertaking which it had so long been the chief object of my wish to carry out. In my letter to the Duke of Sussex, I urged the establishment of permanent stations in Canada, St. Helena, the Cape of Good Hope, the Isle of France, Ceylon, and New Holland, which five years previously I had advanced as good positions. The Royal Society appointed a joint physical and meteorological committee, which not only proposed to the government the establishment of fixed magnetic observatories in both hemispheres, but also the equipment of a naval expedition for magnetic observations in the Antarctic Seas. It is needless to proclaim the obligations of science in this matter to the great activity every regular or irregular manifestation of the terrestrial force is detected by uninterrupted and simultaneous observations. A variation of $\frac{1}{40000}$th of the magnetic intensity is measured, and, at certain epochs, observations are made at intervals of 21 minutes, and continued for twenty-four hours consecutively. A great English astronomer and physicist has calculated[26] that the mass of observations which are in progress will accumulate in the course of three years to 1,958,000. Never before

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of Sir John Herschel, Sabine, Airy, and Lloyd, as well as the powerful support that was afforded by the British Association for the Advancement of Science at their meeting held at Newcastle in 1838. In June, 1839, the Antarctic magnetic expedition, under the command of Captain James Clark Ross, was fully arranged; and now, since its successful return, we reap the double fruits of highly important geographical discoveries around the south pole, and a series of simultaneous observations at eight or ten magnetic stations.

[26]See the article on Terrestrial Magnetism, in the Quarterly Review 1840, vol. Ixvi p 271-312.

has so noble and cheerful a spirit presided over the inquiry into the quantitative relations of the laws of the phenomena of nature. We are, therefore, justified in hoping that these laws, when compared with those which govern the atmosphere and the remoter regions of space, may, by degrees, lead us to a more intimate acquaintance with the genetic conditions of magnetic phenomena. As yet we can only boast of having opened a greater number of paths which may possibly lead to an explanation of this subject. In the physical science of terrestrial magnetism, which must not be confounded with the purely mathematical branch of the study, those persons only will obtain perfect satisfaction who, as in the science of the meteorological processes of the atmosphere, conveniently turn aside the practical bearing of all phenomena that can not be explained according to their own views.

Chapter 19

Aurora Borealis

Terrestrial magnetism, and the electrodynamic forces computed by the intellectual Ampére,[1] stand in simultaneous

[1]Instead of ascribing the internal heat of the Earth to the transition of matter from a vaporlike fluid to a solid condition, which accompanies the formation of the planets, Ampére has provided the idea, which I regard as highly improbable, that the Earth's temper-

and intimate connection with the terrestrial or polar light, as well as with the internal and external heat of our planet, whose magnetic poles may be considered as the poles of cold.[2] The old conjecture

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ature may be the consequence of the continuous chemical action of a nucleus of the metals of the earths and alkalies on the oxidizing external crust. It cannot be doubted, he observes in his masterly Théorie des Phénoménes Electrodynamiques, 1826, p. 199, that electromagnetic currents exist in the interior of the globe, and that these currents are the cause of its temperature. They arise from the action of a central metallic nucleus, composed of the metals discovered by Sir Humphrey Davy, acting on the surrounding oxidized layer.

[2]The remarkable connection between the curvature of the magnetic lines and that of my isothermal lines was first detected by Sir David Brewster. See the Transactions of the Royal Society of Edinburgh, vol. ix., 1821, p. 318, and Treatise on Magnetism, 1837, p. 42, 44, 47, and 268. This distinguished physicist admits two cold poles (poles of maximum Cold) in the northern hemisphere, an American one near Cape Walker (73 lat., 100 W. long.), and an Asiatic one (73 lat., 80 E. long.); whence arise, according to him, two hot and two cold meridians, i.e., meridians of greatest heat and cold. Even in the sixteenth century, Acosta (Historia Natural de las Indias, 1589, lib. i., cap. 17), grounding his opinion on the observations of a very experienced Portuguese pilot, taught that there were four lines without declination. It would seem from the controversy of a Bond (the

hazarded one hundred and twenty-eight years since by Halley,[3] that the Aurora Borealis was a magnetic phenomenon, has acquired empirical certainty from Faraday's brilliant discovery of the evolution of light by magnetic forces. The northern light is preceded by premonitory signs. Thus, in the morning before the occurrence of the phenomenon, the irregular horary course of the magnetic needle generally indicates a disturbance of the equilibrium in the distribution of terrestrial magnetism.[4] When this disturbance

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author of The Longitude Found, 1676) with Beckborrow, that this view in some measure influenced Halley in his theory of four magnetic poles. See my Examen Critique de l'Hist. de la Géographie, t. iii., p. 60.

[3]Halley, in the Philosophical Transactions, vol. xxix. (for 1714-1716, No. 341.

[4][The Aurora Borealis of October 24th, 1847, which was one of the most brilliant ever known in this country, was preceded by great magnetic disturbance. On the 22nd of October the maximum of the

attains a great degree of intensity, the equilibrium of the distribution is restored by a discharge attended by a development of light.

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west declination was 23 10; on the 23rd the position of the magnet was continually changing, and the extreme west declinations were between 220 44 and 23 37; on the night between the 23rd and 24th of October, the changes of position were very large and very frequent, the magnet at times moving across the field so rapidly that a difficulty was experienced in following it. During the day of the 24th of October, there was a constant change of position, but after midnight, when the Aurora began perceptibly to decline in brightness, the disturbance entirely ceased. The changes of position of the horizontal force magnet were as large and as frequent as those of the declination magnet, but the vertical force magnet was at no time so much affected as the other two instruments. See On the Aurora Borealis, as it was seen on Sunday evening, October 24th, 1847, at Blackheath, by James Glaisher, Esq., of the Royal Observatory, Greenwich, in the London, Edinburgh, and Dublin Philos. Mag. and Journal of Science for Nov., 1847. See further, An Account of the Aurora Borealis of October the 24th, 1847, by John H. Morgan, Esq. We must not omit to mention that magnetic disturbance is now registered by a photographic process. The self-registering photographic apparatus used for this purpose in the Observatory at Greenwich was designed by Mr. Brooke, and another ingenious instrument of this kind has been invented by Mr. F. Ronalds, of the Richmond Observatory.] – Tr.

The Aurora[5] itself is, therefore, not to be regarded as an externally manifested cause of this disturbance, but rather as a result of telluric activity, manifested on the one side by the appearance of the light, and on the other by the vibrations of the magnetic needle. The splendid appearance of colored polar light is the act of discharge, the termination of a magnetic storm, as in an electrical storm a development of light—the flash of lightning—indicates the restoration of the disturbed equilibrium in the distribution of

[5]Dove, in Poggend., Annalen, bd. xx., 8. 341; bd. xix., s. 388. The declination needle acts in very nearly the same way as an atmospheric electrometer, whose divergence in like manner shows the increased tension of the electricity before this has become so great as to yield a spark. See, also, the excellent observations of Professor Kamtz, in his Lehrbuch der Meteorologie, bd. iii., s. 511-519, and Sir David Brewster, in his Treatise on Magnetism, p. 280. Regarding the magnetic properties of the galvanic flame, or luminous arch from a Bunsen's carbon and zinc battery, see Casselmann's Beobachtungen (Marburg, 1844), s. 56-62.

the electricity. An electric storm is generally confined to a small space, beyond the limits of which the condition of the atmospheric electricity remains unchanged. A magnetic storm, on the other hand, shows its influence on the course of the needle over large portions of continents, and, as Arago first discovered, far from the spot where the evolution of light was visible. It is not improbable that, as heavily charged threatening clouds, owing to frequent transitions of the atmospheric electricity to an opposite condition, are not always discharged, accompanied by lightning, so likewise magnetic storms may occasion far-extending disturbances in the horary course of the needle, without there being any positive necessity that the equilibrium of the distribution should be restored by explosion, or by the passage of luminous effusions from one of the poles to the equator, or from pole to pole.

In collecting all the individual features of the phenomenon in one general picture, we must not omit to describe the origin and course of a perfectly developed Aurora Borealis. Low down in the distant horizon, about the part of the heavens which is intersected by the magnetic meridian, the sky which was previously clear is at once overcast. A dense wall or bank of cloud seems to rise gradually higher and higher, until it attains an elevation of 8 or 10 degrees. The color of the dark segment passes into brown or violet, and stars are visible through the cloudy stratum, as when a dense smoke darkens the sky. A broad, brightly luminous arch, first white, then yellow, encircles the dark segment; but as the brilliant arch appears subsequently to the smoky gray segment, we cannot agree with Argelander in ascribing the latter to the effect of mere contrast with the bright luminous margin.[6] The highest point of the arch of light is, according to accurate observations made on this subject,[7] not generally in the magnetic meridian itself, but from 5 to 18 toward the direction of the magnetic declination of the place.[8] In northern

[6]Argelander, in the important observations on the northern light embodied in the Vorträge über die physikalisch-ökonomischen Gesellschaft zu Königsberg, bd. i., 1834, s. 257-264.

[7]For an account of the results of the observations of Lottin, Bravais, and Siljerström, who spent a winter at Bosekop, on the coast of Lapland (70 N. lat.), and in 210 nights saw the northern lights 160 times, see the Comptes Rendus de l'Acad. des Sciences, t. x., p. 289, and Martins's Météorologie, 1843, p. 453. See, also, Argelander, in the Vorträge geh. in der Königsberg Gesellschaft, bd. i., s. 259.

[8][Prof Challis, of Cambridge, states that in the Aurora of October 24th, 1847, the streamers all converged toward a single point of the heavens, situated in or very near a vertical circle passing through the magnetic pole. Around this point a corona was formed, the rays of which diverged in all directions from the center, leaving a space free

latitudes, in the immediate vicinity of the magnetic pole, the smokelike conical segment appears less dark, and sometimes is not even seen. Where the horizontal force is the weakest, the middle of the luminous arch deviates the most from the magnetic meridian.

The luminous arch remains sometimes for hours together flashing and kindling in ever-varying undulations, before rays and streamers emanate from it, and shoot up to the zenith. The more intense the discharges of the northern light, the more bright is the play of colors, through all the varying gradations from violet and bluish white to green and crimson. Even in ordinary electricity excited by friction, the sparks are only colored in cases where the explosion is very violent after great

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from light; its azimuth was 18° 41′ from south to east, and its altitude 69° 54′. See Professor Challis, in the Atheneum, Oct. 31, 1847.] – Tr tension. The magnetic columns of flame rise either singly from the luminous arch, blended with black rays similar to thick smoke, or simultaneously in many opposite points of the horizon, uniting together to form a flickering sea of flame, whose brilliant beauty admits of no adequate description, as the luminous waves are every moment assuming new and varying forms. The intensity of this light is at times so great, that Lowenérn (on the 29th of June, 1786) recognized the coruscation of the polar light in bright sunshine. Motion renders the phenomenon more visible. Round the point in the vault of heaven which corresponds to the direction of the inclination of the needle, the beams unite together to form the so-called corona, the crown of the northern light, which encircles the summit of the heavenly canopy with a milder radiance and unflickering emanations of light. It is only in rare instances that a perfect crown or circle is formed, but on its completion the phenomenon has invariably reached its maximum, and the radiations become less frequent, shorter, and more colorless. The crown and the luminous arches break up, and the whole vault of heaven becomes covered with irregularly scattered, broad, faint, almost ashy-gray luminous immovable patches, which in their turn disappear, leaving nothing but a trace of the dark, smokelike segment on the horizon. There often remains nothing of the whole spectacle but a white, delicate cloud with feathery edges, or divided at equal distances into small roundish groups like cirrocumuli.

This connection of the polar light with

the most delicate airy clouds deserves special attention because it shows that the electromagnetic evolution of light is a part of a meteorological process. Terrestrial magnetism here manifests its influence on the atmosphere and on the condensation of aqueous vapor. The fleecy clouds seen in Iceland by Thienemann, and which he considered to be the northern light, have been seen in recent times by Franklin and Richardson near the American north pole, and by Admiral Wrangel on the Siberian coast of the Polar Sea. All remarked that the Aurora flashed forth in the most vivid beams when masses of cirrus strata were hovering in the upper regions of the air, and when these were so thin that their presence could only be recognized by the formation of a halo round the moon. These clouds sometimes range themselves, even by day, in a similar manner to the beams of the Aurora, and then disturb the course of the magnetic needle in the same manner as the latter. On the morning after every distinct nocturnal Aurora, the same superimposed strata of clouds have still been observed that had previously been luminous.[9] The apparently converging polar zones (streaks of clouds in the direction of the magnetic meridian), which constantly occupied my attention during my journeys on the elevated plateaus of Mexico and in Northern Asia, belong proba-

[9]John Franklin, Narrative of a Journey to the Shores of the Polar Sea, in the Years 1819-1822, p. 552 and 597; Thienemann, in the Edinburgh Philosophical Journal, vol. xx., p. 336; Farquharson, in vol. vi., p. 392, of the same journal; Wrangel, Phys. Beob., 8. 59. Parry even saw the great arch of the northern light continue throughout the day. (Journal of a Second Voyage, performed in 1821-1823, p. 156.) Something of the same nature was seen in England on the 9th of September, 1827. A luminous arch, 20 high, with columns proceeding from it, was seen at noon in a part of the sky that had been clear after rain. (Journal of the Royal Institution of Great Britain, 1828, Jan., p. 429.)

bly to the same group of diurnal phenomena.[10]

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[10]On my return from my American travels, I described the delicate cirrocumulus cloud, which appears uniformly divided, as if by the action of repulsive forces, under the name of polar bands (bandes polaires), because their perspective point of convergence is mostly at first in the magnetic pole, so that the parallel rows of fleecy clouds follow the magnetic meridian. One peculiarity of this mysterious phenomenon is the oscillation, or occasionally the gradually progressive motion, of the point of convergence. It is usually observed that the bands are only fully developed in one region of the heavens, and they are seen to move first from south to north, and then gradually from east to west. I could not trace any connection between the advancing motion of the bands and alterations of the currents of air in the higher regions of the atmosphere. They occur when the air is extremely calm and the heavens are quite serene, and are much more common under the tropics than in the temperate and frigid zones. I have seen this phenomenon on the Andes, almost under the equator, at an elevation of 15,920 feet, and in Northern Asia, in the plains of Krasnojarski, south of Buchtarminsk, so similarly developed, that we must regard the influences producing it as very widely distributed, and as depending on general natural forces. See the important observations of Kaimtz (Vorlesungen uber Meteorologie, 1840, s. 146), and the more recent ones of Martins and Bravais (Météorologie, 1843, p. 117). In south polar bands, composed of very delicate clouds, observed by Arago at Paris on the 23rd of June, 1844, dark rays shot upward from an arch running east and west. We

Southern lights have often been seen in England by the intelligent and indefatigable observer Dalton, and northern lights have been observed in the southern hemisphere as far as 45 latitude (as on the 14th of January, 1831). On occasions that are by no means of rare occurrence, the equilibrium at both poles has been simultaneously disturbed. I have discovered with certainty that northern polar lights have been seen within the tropics in Mexico and Peru. We must distinguish between the sphere of simultaneous visibility of the phenomenon and the zones of the Earth where it is seen almost nightly. Every observer no doubt sees a separate Aurora of his own, as he sees a separate rainbow. A great portion of the Earth simul-

have missed made mention of black rays, resembling dark smoke, as occurring in brilliant nocturnal northern lights.

taneously engenders these phenomena of emanations of light. Many nights may be instanced in which the phenomenon has been simultaneously observed in England and in Pennsylvania, in Rome and in Pekin. When it is stated that Auroras diminish with the decrease of latitude, the latitude must be understood to be magnetic, and as measured by its distance from the magnetic pole. In Iceland, in Greenland, Newfoundland, on the shores of the Slave Lake, and at Fort Enterprise in Northern Canada, these lights appear almost every night at certain seasons of the year, celebrating with their flashing beams, according to the mode of expression common to the inhabitants of the Shetland Isles, a merry dance in heaven.[11]

[11] The northern lights are called by the Shetland Islanders the merry dancers. (Kendal, in the Quarterly Journal of Science, new series, vol. iv., p. 395.)

While the Aurora is a phenomenon of rare occurrence in Italy, it is frequently seen in the latitude of Philadelphia (39 57), owing to the southern position of the American magnetic pole. In the districts which are remarkable, in the New Continent and the Siberian coasts, for the frequent occurrence of this phenomenon, there are special regions or zones of longitude in which the polar light is particularly bright and brilliant.[12] The existence of local influences cannot, therefore, be denied in these cases. Wrangel saw the brilliancy diminish as he left the shores of the Polar Sea, about NischneKolymsk. The observations made in the North Polar expedition appear to prove that in the immediate vicinity of the magnetic pole the development of light

[12]See Munckes excellent work in the new edition of Gehlers Physik Werterbuch, bd. vii., i., 8. 113268, and especially s. 158.

is not in the least degree more intense or frequent than at some distance from it.

The knowledge which we at present possess of the altitude of the polar light is based on measurements which, from their nature, the constant oscillation of the phenomenon of light, and the consequent uncertainty of the angle of parallax, are not deserving of much confidence. The results obtained, setting aside the older data, fluctuate between several miles and an elevation of 3000 or 4000 feet; and, in all probability, the northern lights at different times occur at very different elevations.[13] The most recent observers are dis-

[13] Farquharson in the Edinburgh Philos. Journal, vol. xvi., p. 304; Philos. Transactions for 1829, p. 113.

[The height of the bow of light of the Aurora seen at the Cambridge Observatory, March 19, 1847, was determined by Professors Challis, of Cambridge, and Chevallier, of Durham, to be 177 miles above the surface of the Earth. See the notice of this meteor in An Account of the Aurora Borealis of Oct. 24, 1847, by John H. Morgan, posed to place the phenomenon in the region of clouds, and not on the confines of the atmosphere; and they even believe that the rays of the Aurora may be affected by winds and currents of air, if the phenomenon of light, by which alone the existence of an electromagnetic current is appreciable, be actually connected with material groups of vesicles of vapor in motion, or, more correctly speaking, if light penetrate them, passing from one vesicle to another. Franklin saw near Great Bear Lake a beaming northern light, the lower side of which he thought illuminated a stratum of clouds, while, at a distance of only eighteen geographical miles, Kendal, who was on watch throughout the whole night, and never lost sight of the sky, perceived no phenomenon of light. The as-

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Esq., 1848.] – Tr.

sertion, so frequently maintained of late, that the rays of the Aurora have been seen to shoot down to the ground between the spectator and some neighboring hill, is open to the charge of optical delusion, as in the cases of strokes of lightning or of the fall of fireballs.

Whether the magnetic storms, whose local character we have illustrated by such remarkable examples, share noise as well as light in common with electric storms, is a question that has become difficult to answer, since implicit confidence is no longer yielded to the relations of Greenland whale fishers and Siberian fox hunters. Northern lights appear to have become less noisy since their occurrences have been more accurately recorded. Parry, Franklin, and Richardson, near the north pole; Thienemann in

Iceland; Gieseke in Greenland; Letuc and Bravais, near the North Cape; Wrangel and Anjou, on the coast of the Polar Sea, have together seen the Aurora thousands of times, but never heard any sound attending the phenomenon. If this negative testimony should not be deemed equivalent to the positive counter evidence of Hearne on the mouth of the Copper River and of Henderson in Iceland, it must be remembered that, although Hood heard a noise as of quickly moved musket balls and a slight cracking sound during an Aurora, he also noticed the same noise on the following day, when there was no northern light to be seen; and it must not be forgotten that Wrangel and Gieseke were fully convinced that the sound they had heard was to be ascribed to the contraction of the ice and the crust of the snow on the sudden cooling of the atmosphere. The belief in a crackling sound has arisen, not among the people generally, but rather among learned travelers, because in earlier times the northern light was declared to be an effect of atmospheric electricity, on account of the luminous manifestation of the electricity in rarefied space, and the observers found it easy to hear what they wished to hear. Recent experiments with very sensitive electrometers have hitherto, contrary to the expectation generally entertained, yielded only negative results. The condition of the electricity in the atmosphere[14] is not found to be changed during

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[14] [Mr. James Glaisher, of the Royal Observatory, Greenwich, in his interesting Remarks on the Weather during the Quarter ending December 31st, 1847, says, It is a fact well worthy of notice, that from the beginning of this quarter till the 20th of December, the electricity of the atmosphere was almost always in a neutral state, so that no signs of electricity were shown for several days together by any of the electrical instruments. During this period there were eight exhi-

the most intense Aurora; but, on the other hand, the three expressions of the power of terrestrial magnetism, declination, inclination, and intensity, are all affected by polar light, so that in the same night, and at different periods of the magnetic development, the same end of the needle is both attracted and repelled. The assertion made by Parry, on the strength of the data yielded by his observations in the neighborhood of the magnetic pole at Melville Island, that the Aurora did not disturb,

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bitions of the Aurora Borealis, of which one was the peculiarly bright display of the meteor on the 24th of October. These frequent exhibitions of brilliant Aurore seem to depend upon many remarkable meteorological relations, for we find, according to Mr. Glaisher's statement in the paper to which we have already alluded, that the previous fifty years afford no parallel season to the closing one of 1847. The mean temperature of evaporation and of the dew point, the mean elastic force of vapor, the mean reading of the barometer, and the mean daily range of the readings of the thermometers in dir, were all greater at Greenwich during that season of 1847 than the average range of many preceding years.] – Tr.

but rather exercised a calming influence on the magnetic needle, has been satisfactorily refuted by Parry's own more exact researches,[15] detailed in his journal, and by the admirable observations of Richardson, Hood, and Franklin in Northern Canada, and lastly by Bravais and Lottin in Lapland. The process of the Aurora is, as has already been observed, the restoration of a disturbed condition of equilibrium. The effect on the needle is different according to the degree of intensity of the explosion. It was only unappreciable at the gloomy winter station of Bosekop when the phenomenon of light was very faint and low in the horizon. The shooting cylinders of rays have been aptly compared to the flame which rises in the closed circuit of a voltaic pile between two points of car-

[15] Kamtz, Lehrbuch der Meteorologie, bd. iii., s. 498 und 501.2

bon at a considerable distance apart, or, according to Fizeau, to the flame rising between a silver and a carbon point, and attracted or repelled by the magnet. This analogy certainly sets aside the necessity of assuming the existence of metallic vapors in the atmosphere, which some celebrated physicists have regarded as the substratum of the northern light.

When we apply the indefinite term polar light to the luminous phenomenon which we ascribe to a galvanic current, that is to say, to the motion of electricity in a closed circuit, we merely indicate the local direction in which the evolution of light is most frequently, although by no means invariably, seen. This phenomenon derives the greater part of its importance from the fact that the Earth becomes self-luminous, and that as a planet, besides the light which it receives from the central body, the Sun, it shows itself capable in itself of developing light. The intensity of the terrestrial light, or, rather, the luminosity which is diffused, exceeds, in cases of the brightest colored radiation toward the zenith, the light of the Moon in its first quarter. Occasionally, as on the 7th of January, 1831, printed characters could be read without difficulty. This almost uninterrupted development of light in the Earth leads us by analogy to the remarkable process exhibited in Venus. The portion of this planet which is not illumined by the Sun often shines with a phosphorescent light of its own. It is not improbable that the Moon, Jupiter, and the comets shine with an independent light, besides the reflected solar light visible through the polariscope. Without speaking of the problematical but yet ordinary mode in which the sky is illuminated, when a low cloud may be seen to shine with an uninterrupted flickering light for many minutes together, we still meet with other instances of terrestrial development of light in our atmosphere. In this category we may reckon the celebrated luminous mists seen in 1783 and 1831; the steady luminous appearance exhibited without any flickering in great clouds observed by Rozier and Beccaria; and lastly, as Arago[16] well remarks, the faint diffused light which guides the steps of the traveler in cloudy, starless, and moonless nights in autumn and winter, even when there is no snow on

[16]Arago, on the dry fogs of 1783 and 1831, which illuminated thenight, in the Annuaire du Bureau des Longitudes, 1832, p.246 and 2503and, regarding extraordinary luminous appearances in clouds withoutstorms, see Notices sur la Tonnerre, in the Annuaire pour Van. 1838,p. 279-285.

the ground. As in polar light or the electromagnetic storm, a current of brilliant and often colored light streams through the atmosphere in high latitudes, so also in the torrid zones between the tropics, the ocean simultaneously develops light over a space of many thousand square miles. Here the magical effect of light is owing to the forces of organic nature. Foaming with light, the eddying waves flash in phosphorescent sparks over the wide expanse of waters, where every scintillation is the vital manifestation of an invisible animal world. So varied are the sources of terrestrial light. Must we still suppose this light to be latent, and combined in vapors, in order to explain Moser's images produced at a distance—a discovery in which reality has hitherto manifested itself like a mere phantom of the imagination.

Chapter 20

Geognostic Phenomena

As the internal heat of our planet is connected on the one hand with the generation of electro-magnetic currents and the process of terrestrial light (a consequence of the magnetic storm), it, on the other hand, discloses to us the chief source of geognostic phenomena. We shall consider these in their connection with and their transition from merely dynamic disturbances, from the elevation of whole continents and mountain chains to the development and effusion of gaseous and liquid fluids, of hot mud, and of those heated and molten earths which become solidified into crystalline mineral masses. Modern geognosy, the mineral portion of terrestrial physics, has made no slight advance in having investigated this connection of phenomena. This investigation has led us away from the delusive hypothesis, by which it was customary formerly to endeavor to explain, individually, every expression of force in the terrestrial globe - it shows us the connection of the occurrence of heterogeneous substances with that which only appertains to changes in space (disturbances or elevations), and groups together phenomena which at first sight appeared most heterogeneous, as thermal springs, effusion of carbonic acid and sulphurous vapor, innocuous salses (mud eruptions), and the dreadful devastations of volcanic mountains.[1] In a general view of nature, all these phenomena are fused together in one sole idea of the reaction of the interior of a planet on its external surface. We thus recognize in the depths of the earth, and in the increase of temperature with the increase of depth from the surface, not only the germ of disturbing movements, but also of the gradual elevation of whole continents (as mountain chains on long fissures), of volcanic eruptions, and

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[1]See Mantell's Wonders of Geology, 1848, vol. i., p. 34, 36, 105; also Lyell's Principles of Geology, vol. ii., and Daubeney On Volcanoes, 2d ed., 1848, Part ii, ch. xxxii., xxxiii.

of the manifold production of mountains and mineral masses. The influence of this reaction of the interior on the exterior is not, however, limited to inorganic nature alone. It is highly probable that, in an earlier world, more powerful emanations of carbonic acid gas, blended with the atmosphere, must have increased the assimilation of carbon in vegetables, and that an inexhaustible supply of combustible matter (lignites and carboniferous formations) must have been thus buried in the upper strata of the earth by the revolutions attending the destruction of vast tracts of forest. We likewise perceive that the destiny of mankind is in part dependent on the formation of the external surface of the earth, the direction of mountain tracts and highlands, and on the distribution of elevated continents. It is thus granted to the inquiring mind to pass from link to link along the chain of phenomena until it reaches the period when, in the solidifying process of our planet, and in its first transition from the gaseous form to the agglomeration of matter, that portion of the inner heat of the Earth was developed, which does not belong to the action of the Sun.

Chapter 21

Earthquakes

In order to give a general delineation of the causal connection of geognostical phenomena, we will begin with those whose chief characteristic is dynamic, consisting in motion and in change in space. Earthquakes manifest themselves by quick and successive vertical, or horizontal, or rotatory vibrations.[1] In the very considerable number of earthquakes which I have experienced in both hemispheres, alike on land and at sea, the two first-named kinds of motion have often appeared to me to occur simultaneously. The mine-like explosion – the vertical action from below upward – was most strikingly manifested in the overthrow of the town of Riobamba in 1797, when the bodies of many of the inhabitants were found to have been hurled to Cullca, a hill several hundred feet in height, and on the opposite side of the River Lican. The propagation is most generally effected by undulations in a linear direction.[2] with a velocity of from twenty to twenty-eight miles in a minute, but partly in circles of commo-

[1] [See Daubeney On Volcanoes, 2d ed., 1848, p. 509.] – Tr.

[2] [On the linear direction of earthquakes, see Daubeney On Volcanoes, p. 515.] – Tr.

tion or large ellipses, in which the vibrations are propagated with decreasing intensity from a center toward the circumference. There are districts exposed to the action of two intersecting circles of commotion. In Northern Asia, where the Father of History,[3] and subsequently Theophylactus Simocatta,[4] described the districts of Scythia as free from earthquakes, I have observed the metalliferous portion of the Altai Mountains under the influence of a twofold focus of commotion, the Lake of Baikal, and the volcano of the Celestial

[3]Herod, iv., 28. The prostration of the colossal statue of Memnon, which has been again restored (Letronne, La Statue Vocale de Memnon, 1835, p. 25, 26), presents a fact in opposition to the ancient prejudice that Egypt is free from earthquakes (Pliny, ii., 80); but the valley of the Nile does lie external to the circle of commotion of Byzantium, the Archipelago, and Syria (Ideler ad Aristot., Meteor., p. 584).

[4]SaintMartin, in the learned notes to Lebeau, Hist. du Bas Empire, t. ix., p. 401.

Mountain (Thianschan).[5] When the circles of commotion intersect one another - when, for instance, an elevated plain lies between two volcanoes simultaneously in a state of eruption, several wave systems may exist together, as in fluids, and not mutually disturb one another. We may even suppose interference to exist here, as in the intersecting waves of sound. The extent of the propagated waves of commotion will be increased on the upper surface of the earth, according to the general law of mechanics, by which, on the transmission of motion in elastic bodies, the stratum lying free on the one side endeavors to separate itself from the other strata.

Waves of commotion have been investi-

[5]Humboldt, Asie Centrale, t. ii., p. 110-118. In regard to the difference between agitation of the surface and of the strata lying beneath it, see Gay-Lussac, in the Annales de Chimie et de Physique, t. xxil., p. 429.

gated by means of the pendulum and the seismometer[6] with tolerable accuracy in respect to their direction and total intensity, but by no means with reference to the internal nature of their alternations and their periodic intumescenze. In the city of Quito, which lies at the foot of a still active volcano (the Rucu Pichincha), and at an elevation of 9540 feet above the level

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[6][This instrument, in its simplest form, consists of a basin filled with some viscid liquid, which, on the occurrence of a shock of an earthquake of sufficient force to disturb the equilibrium of the building in which it is placed, is tilted on one side, and the liquid made to rise in the same direction, thus showing by its height the degree of the disturbance. Professor J. Forbes has invented an instrument of this nature, although on a greatly improved plan. It consists of a vertical metal rod, having a ball of lead movable upon it. It is supported upon a cylindrical steel wire, which may be compressed at pleasure by means of a screw. A lateral movement, such as that of an earthquake, which carries forward the base of the instrument, can only act upon the ball through the medium of the elasticity of the wire, and the direction of the displacement will be indicated by the plane of vibration of the pendulum. A self-registering apparatus is attached to the machine. See Professor J. Forbes's account of his invention in Edinb Phil. Trans., vol. xv., Part i.] – Tr.

of the sea, which has beautiful cupolas, high vaulted churches, and massive edifices of several stories, I have often been astonished that the violence of the nocturnal earthquakes so seldom causes fissures in the walls, while in the Peruvian plains oscillations apparently much less intense injure low reed cottages. The natives, who have experienced many hundred earthquakes, believe that the difference depends less upon the length or shortness of the waves, and the slowness or rapidity of the horizontal vibrations,[7] than on the uniformity of the motion in opposite directions. The circling rotatory commotions are the most uncommon, but, at the same

[7] Tutissimum est eum vibrat crispante dificiorum crepitu; et cum intumescit assurgens alternoque motu residet, innoxium et cum concur. rentia tecta contrario ictu arietant; quoniam alter motus alteri renititur. Undantis inclinatio et fluctus more quedam volutatio infesta est, aut cum in unam partem totus se motus impellit. Plin., ii., 82.

time, the most dangerous. Walls were observed to be twisted, but not thrown down; rows of trees turned from their previous parallel direction; and fields covered with different kinds of plants found to be displaced in the great earthquake of Riobamba, in the province of Quito, on the 4th of February, 1797, and in that of Calabria, between the 5th of February and the 28th of March, 1782. The phenomenon of the inversion or displacement of fields and pieces of land, by which one is made to occupy the place of another, is connected with a translatory motion or penetration of separate terrestrial strata. When I made the plan of the ruined town of Riobamba, one particular spot was pointed out to me, where all the furniture of one house had been found under the ruins of another. The loose earth had evidently moved like a fluid in currents, which must be assumed to have been directed first downward, then horizontally, and lastly upward. It was found necessary to appeal to the Audencia, or Council of Justice, to decide upon the contentions that arose regarding the proprietorship of objects that had been removed to a distance of many hundred toises.

In countries where earthquakes are comparatively of much less frequent occurrence (as, for instance, in Southern Europe), a very general belief prevails, although unsupported by the authority of inductive reasoning,[8] that a calm, an op-

[8]Even in Italy they have begun to observe that earthquakes are unconnected with the state of the weather, that is to say, with the appearance of the heavens immediately before the shock. The numerical results of Friedrich Hoffmann (Hinterlassene Werke, bd. ii., 366375) exactly correspond with the experience of the Abbate Scina of Palermo. I have myself several times observed reddish clouds on the day of an earthquake, and shortly before it; on the 4th of Novem-

ber, 1799, I experienced two sharp shocks at the moment of a loud clap of thunder. (Relat. Hist., liv. iv., chap. 10.) The Turin physicist, Vassalli Eandi, observed Volta's electrometer to be strongly agitated during the protracted earthquake of Pignerol, which lasted from the 2d of April to the 17th of May, 1808; Journal de Physique, t. Ixvii., p. 291. But these indications presented by clouds, by modifications of atmospheric electricity, or by calms, can not be regarded as generally or necessarily connected with earthquakes, since in Quito, Peru, and Chili, as well as in Canada and Italy, many earthquakes are observed along with the purest and clearest skies, and with the freshest land and sea breezes. But if no meteorological phenomenon indicates the coming earthquake either on the morning of the shock or a few days previously, the influence of certain periods of the year (the vernal and autumnal equinoxes), the commencement of the rainy season in the tropics after long drought, and the change of the monsoons (according to general belief), can not be overlooked, even though the genetic connection of meteorological processes with those going on in the interior of our globe is still enveloped in obscurity. Numerical inquiries on the distribution of earthquakes throughout the course of the year, such as those of Von Hoff, Peter Merian, and Friedrich Hoffmarn, bear testimony to their frequency at the periods of the equinoxes. It is singular that Pliny, at the end of his fanciful theory of earthquakes, names the entire frightful phenomenon a subterranean storm; not so much in consequence of the rolling sound which frequently accompanies the shock, as because the elastic forces, concussive by their tension, accumulate in the interior of the earth when they are absent in the atmosphere. "Ventos in causa esse non dubium reor. Neque enim unquam intremiscunt terre, nisi sopito mari, pressive heat, and a misty horizon, are always the forerunners of this phenomenon. The fallacy of this popular opinion is not only refuted by my own experience, but likewise by the observations of all those who have lived many years in districts where, as in Cumana, Quito, Peru, and Chili, the earth is frequently and violently agitated. I have felt earthquakes in clear air and a fresh east wind, as well as in rain and thunderstorms. The regularity of the hourly changes in the declination of the magnetic needle and in the atmospheric pressure remained undisturbed between

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coeloque adeo tranquillo, ut volatus avium non pendeant, subtracto omni spiritu qui vehit; nec unquam nisi post ventos conditos, scilicet in venas et cavernas ejus occulto afflatu. Neque aliud est in terra tremor, quam in nube tonitruum; nec hiatus aliud quam cum fulmen erumpit, incluso spiritu luctante et ad libertatem exire nitente." (Plin., ii., 79.) The germs of almost everything that has been observed or imagined on the causes of earthquakes, up to the present day, may be found in Seneca, Nat. Quest., vi., 431.

the tropics on the days when earthquakes occurred.[9] These facts agree with the observations made by Adolph Erman (in the temperate zone, on the 8th of March, 1829) on the occasion of an earthquake at Irkutsk, near the Lake of Baikal. During the violent earthquake of Cumana, on the 4th of November, 1799, I found the declination and the intensity of the magnetic force alike unchanged, but, to my surprise, the inclination of the needle was diminished about 48′.[10] There was no ground to suspect an error in the calculation, and yet, in the many other earthquakes which I have experienced on the elevated plateaus of Quito and Lima, the inclination as well as the other elements of terrestrial mag-

[9]I have given proof that the course of the horary variations of thevarometer is not ae before or after earthquakes, in my Relat. Hist.,6 1, p. 311 and 513.

[10]Humboldt, Relat. Hist., t. i., p. 515-517.

netism remained always unchanged. Although, in general, the processes at work within the interior of the earth may not be announced by any meteorological phenomena or any special appearance of the sky, it is, on the contrary, not improbable, as we shall soon see, that in cases of violent earthquakes some effect may be imparted to the atmosphere, in consequence of which they can not always act in a purely dynamic manner.

During the long-continued trembling of the ground in the Piedmontese valleys of Pelis and Clusson, the greatest changes in the electric tension of the atmosphere were observed while the sky was cloudless. The intensity of the hollow noise which generally accompanies an earthquake does not increase in the same degree as the force of the oscillations. I have ascertained with certainty that the great shock of the earthquake of Riobamba (4th Feb., 1797), one of the most fearful phenomena recorded in the physical history of our planet, was not accompanied by any noise whatever. The tremendous noise (el gran ruido) which was heard below the soil of the cities of Quito and Ibarra, but not at Tacunga and Hambato, nearer the center of the motion, occurred between eighteen and twenty minutes after the actual catastrophe. In the celebrated earthquake of Lima and Callao (28th of October, 1746), a noise resembling a subterranean thunderclap was heard at Truxillo a quarter of an hour after the shock, and unaccompanied by any trembling of the ground. In like manner, long after the great earthquake in New Granada, on the 16th of November, 1827, described by Boussingault, subterranean detonations were heard in the whole valley of Caucaduring twenty or thirty seconds, unattended by motion. The nature of the noise varies also very much, being either rolling, or rustling, or clanking like chains when moved, or like near thunder, as, for instance, in the city of Quito; or, lastly, clear and ringing, as if obsidian or some other vitrified masses were struck in subterranean cavities. As solid bodies are excellent conductors of sound, which is propagated in burned clay, for instance, ten or twelve times quicker than in the air, the subterranean noise may be heard at a great distance from the place where it has originated. In Caracas, in the grassy plains of Calabozo, and on the banks of the Rio Apure, which falls into the Orinoco, a tremendously loud noise, resembling thunder, was heard, unaccompanied by an earthquake, over a district of land 9200 square miles in extent, on the 30th of April, 1812, while at a distance of 632 miles to the northeast, the volcano of St. Vincent, in the small Antilles, poured forth a copious stream of lava. With respect to distance, this was as if an eruption of Vesuvius had been heard in the north of France. In the year 1744, on the great eruption of the volcano of Cotopaxi, subterranean noises, resembling the discharge of cannon, were heard in Honda, on the Magdalena River. The crater of Cotopaxi lies not only 18,000 feet higher than Honda, but these two points are separated by the colossal mountain chain of Quito, Pasto, and Popayan, no less than by numerous valleys and clefts, and they are 436 miles apart. The sound was certainly not propagated through the air, but through the earth, and at a great depth. During the violent earthquake of New Granada, in February, 1835, subterranean thunder was heard simultaneously at Popayan, Bogota, Santa Marta, and Caracas (where it continued for seven hours without any movement of the ground), in Haiti, Jamaica, and on the Lake of Nicaragua.

These phenomena of sound, when unattended by any perceptible shocks, produce a peculiarly deep impression even onpersons who have lived in countries where the earth has beenfrequently exposed to shocks. A striking and unparalleled instance of uninterrupted subterranean noise, unaccompanied byany trace of an earthquake, is the phenomenon known in theMexican elevated plateaux by the name of the roaring andthe subterranean thunder (bramidos y truenos subterrancos)of Guanaxuato.[11] This cele-

[11]On the bramidos of Guanaxuato, see my Essai Polit. sur la Nouv.Espagne, t. i., p. 303. The subterranean noise, unaccompanied withany appreciable shock, in the deep mines and on the surface (the townof Guanaxuato lies 6830 feet above the level of the sea), was not heardin the neighboring elevated plains, but only in the mountainous partsof the Sierra, from the Cuesta de los Aguilares, near Marfil, to the northof Santa Rosa. There were individual parts of the Sierra 2428 milesnorthwest of Gaanaxuato, to the other side of Chichimequillo, near theboiling spring of San José de Comangillas, to which the waves of sounddid not extend. Extremely stringent measures were adopted by themagistrates of the large mountain towns on the 14th of January, 1784,wheu the terror produced by these subterranean thunders was at itsheight. The flight of a wealthy family shall be punished with a fineof 1000 piasters, and that of a poor family with two months imprisonment. The militia shall bring back the fugitives. One of the mostremarkable points about the whole affair is the opinion which the magistrates (el cabildo) cherished of their own superior knowledge. Inone of their proclamas, I find the expression, The magistrates, in theirwisdom (en su sabiduria), will at once know when there is actual danger, and will give orders for Hight; for the present, let processions beinstituted. The terror excited by the tremor gave rise to a famine,since it prevented the importation of corn from the tablelands, whereit abounded. The ancients were also aware that noises sometimes existed without earthquakes.Aristot., Meteor., ii., p. 802; Plin., ii., 80.Tho singular noise that was heard from March, 1822, to September,1824, in the Dalmatian island Meleda (sixteen miles from Ra-

brated and rich mountain citylies far removed from any active voleano. The noise beganabout midnight on the 9th of Janu-agy, 1784, and continuedfor a month. I have been enabled to give a circumstantial description of it from the report of many witnesses, and fromthe documents of the municipality, of which I was allowed tomake use. From the 13th to the 16th of January, it seemedto the inhabitants as if heavy clouds lay beneath their feet,from which issued alternate slow rolling sounds and short,quick claps of thunder. The noise abated as gradually as ithad begun. It was limited to a small space, and was notheard in a basaltic district at the distance of a few miles.Almost all the mhabitants, in terror, left the city, in whichlarge

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gusa), andon which Partsch has thrown much light, was occasionally accompaniedby shocks.

masses of silver ingots were stored ; but the most courageous, and those more accustomed to subterranean thunder,soon returned, in order to drive off the bands of robbers whohad attempted to possess themselves of the treasures of thecity. Neither on the surface of the earth, nor in mines 1600feet in depth, was the slightest shock to be perceived. Nosimilar noise had ever before been heard on the elevated tableland of Mexico, nor has this terrific phenomenon since occurredthere. Thus clefts are opened or closed in the interior of theearth, by which waves of sound penetrate to us or are impededin their propagation.

The activity of an igneous mountain, however terrific andpicturesque the spectacle may be which it presents to our contemplation, is always limited to a very small space. It is farotherwise with earthquakes, which, although scarcely perceptible to the eye, nevertheless simultaneously propagate theirwaves to a distance of many thousand miles. The greatearthquake which destroyed the city of Lisbon on the Ist ofNovember, 1755, and whose effects were so admirably investigated by the distinguished philosopher Emmanuel Kant, wasfelt in the Alps, on the coast of Sweden, in the Antilles, Antigua, Barbadoes, and Martinique; in the great CanadianLakes, in Thuringia, in the flat country of Northern Germany, and in the small inland lakes on the shores of the Baltic.[12] Remote springs were inter-

[12] [It has been computed that the shock of this earthquake pervadedan area of 700,000 miles, or the twelfth part of the circumference of theglobe. This dreadful shock lasted only five minutes it happened aboutnine oclock in the morning of the Feast of All Saints, when almost thewhole population was within the churches, owing to which circumstance no less than 30,000 persons perished by the fall of these edificea.See Daubeney On Volcanoes, p. 514517.] – Tr.

rupted in their flow, a phenomenon attending earthquakes which had been noticed amongthe ancients by Demetrius the Callatian. The hot springs ofTéplitz dried up, and returned, inundating every thing around,and having their waters colored with iron ocher. In Cadiz the sea rose to an elevation of sixtyfour feet, while in the Anlilles, where the tide usually rises only from twentysix totwentyeight inches, it suddenly rose above twenty feet, thewater being of an inky blackness. Jt has been computed thaton the 1st of November, 1755, a portion of the Earths surface, four times greater than that of Europe, was simultaneously shaken. As yet there is no manifestation of force knownto us, including even the murderous inventions of our ownrace, by which a greater number of people have been kilied inthe short space of a few minutes sixty thousand were destroyed in Sicily in 1693, from thirty to forty thousand in theearthquake of Riobamba in 1797, and probably five times asmany in Asia Minor and Syria, under Tiberius and Justinianthe elder, about the years 19 and 526.

There are instances in which the earth has been shaken for many successive days in the chain of the Andes in South America, but I am only acquainted with the following cases in which shocks that have been felt almost every hour for months together have occurred far from any volcano, as, for instance, on the eastern declivity of the Alpine chain of Mount Cenis, at Fenestrelles and Pignerol, from April, 1808; between New Madrid and Little Prairic,[13]

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[13]Drake, Nat. and Statist. View of Cincinnati, p. 232238; Mitchell,in the Transactions of the Lit. and Philos. Soc. of New York, vol. i., p.281308. In the Piedmontese county of Pignerol, glasses of

north of Cincinnati, in the United States of America, in December, 1811, as well as through the whole winter of 1812; and in the Pachalik of Aleppo, in the months of August and September, 1822. As the mass of the people are seldom able to rise to general views, and are consequently always disposed to ascribe great phenomena to local telluric and atmospheric processes, wherever the shaking of the earth is continued for a long time, fears of the eruption of a new volcano are awakened. In some few cases, this apprehension has certainly proved to be well grounded, as, for instance, in the sudden elevation of volcanic islands, and as we see in the elevation of the volcano of Jorullo, a mountain elevated 1684 feet above the ancient level of the neighboring plain, on the 29th

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water, filledty the very brim, 2xhibited for hours a continuous motion.

of September, 1759, after ninety days of earthquake and subterranean thunder.

If we could obtain information regarding the daily condition of all the earth's surface, we would probably discover that the earth is almost always undergoing shocks at some point of its surface, and is continually influenced by the reaction of the interior on the exterior. The frequency and general prevalence of a phenomenon which is probably dependent on the raised temperature of the deepest molten strata explain its independence of the nature of the mineral masses in which it manifests itself. Earthquakes have even been felt in the loose alluvial strata of Holland, as in the neighborhood of Middleburg and Vliessingen on the 23rd of February, 1828. Granite and mica slate are shaken as well as limestone and sandstone, or as trachyte and amygdaloid. It is not, therefore, the chemical nature of the constituents, but rather the mechanical structure of the rocks, which modifies the propagation of the motion, the wave of commotion. Where this wave proceeds along a coast, or at the foot and in the direction of a mountain chain, interruptions at certain points have sometimes been remarked, which manifested themselves during the course of many centuries. The undulation advances in the depths below, but is never felt at the same points on the surface. The Peruvians[14] say of these unmoved up-

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[14]In Spanish they say, "rocas que hacen puente". With this phenomenon of non-propagation through superior strata is connected the remarkable fact that in the beginning of this century shocks were felt in the deep silver mines at Marienberg, in the Saxony mining district, while not the slightest trace was perceptible at the surface. The miners ascended in a state of alarm. Conversely, the workmen in the mines of Falun and Persberg felt nothing of the shocks which in November, 1823, spread dismay among the inhabitants above

per strata that they form a bridge. As the mountain chains appear to be raised on fissures, the walls of the cavities may perhaps favor the direction of undulations parallel to them; occasionally, however, the waves of commotion intersect several chains almost perpendicularly. Thus we see them simultaneously breaking through the littoral chain of Venezuela and the Sierra Parime. In Asia, shocks of earthquakes have been propagated from Lahore and from the foot of the Himalaya (22nd of January, 1832) transversely across the chain of the Hindoo Chou to Badakschan, the upper Oxus, and even to Bokhara.[15] The circles of commotion unfortunately expand occasionally in consequence of a single

ground.

[15]Sir Alex. Burnes, Travels in Bokhara, vol. i., p. 18; and Wathen Mem. on the Usbek State, in the Journ l of the Asiatic Society of Bengai, vol. iii., p. 337.

and unusually violent earthquake. It is only since the destruction of Cumana, on the 14th of December, 1797, that shocks on the southern coast have been felt in the mica slate rocks of the peninsula of Maniquarez, situated opposite to the chalk hills of the mainland. The advance from south to north was very striking in the almost uninterrupted undulations of the soil in the alluvial valleys of the Mississippi, the Arkansas, and the Ohio, from 1811 to 1813. It seemed here as if subterranean obstacles were gradually overcome, and that the way being once opened, the undulatory movement could be freely propagated.

Although earthquakes appear at first sight to be simply dynamic phenomena of motion, we yet discover, from well-attested facts, that they are not only able to elevate a whole district above its ancient level (as, for instance, the Ulla Bund, after the earthquake of Cutch, in June, 1819, east of the Delta of the Indus, or the coast of Chili, in November, 1822), but we also find that various substances have been ejected during the earthquake, such as hot water at Catania in 1818; hot steam at New Madrid, in the Valley of the Mississippi, in 1812; irrespirable gases, Mofettes, which injured the flocks grazing in the chain of the Andes; mud, black smoke, and even flames, at Messina in 1781, and at Cumana on the 14th of November, 1797. During the great earthquake of Lisbon, on the 1st of November, 1755, flames and columns of smoke were seen to rise from a newly-formed fissure in the rock of Alvidras, near the city. The smoke in this case became more dense as the subterranean noise increased in intensity.[16] At the destruc-

[16]Philos. Transact, vol. xlix. p. 414.

tion of Riobamba, in the year 1797, when the shocks were not attended by any outbreak of the neighboring volcano, a singular mass called the Moya was uplifted from the earth in numerous continuous conical elevations, the whole being composed of carbon, crystals of augite, and the silicious shields of infusoria. The eruption of carbonic acid gas from fissures in the Valley of the Magdalene, during the earthquake of New Granada, on the 16th of November, 1827, suffocated many snakes, rats, and other animals. Sudden changes of weather, such as the occurrence of the rainy season in the tropics, at an unusual period of the year, have sometimes succeeded violent earthquakes in Quito and Peru. Do gaseous fluids rise from the interior of the earth and mix with the atmosphere, or are these meteorological processes the action of atmospheric electricity disturbed by the earthquake? In the tropical regions of America, where sometimes not a drop of rain falls for ten months together, the natives consider the repeated shocks of earthquakes, which do not endanger the low reed huts, as auspicious harbingers of fruitfulness and abundant rain.

The intimate connection of the phenomena which we have considered is still hidden in obscurity. Elastic fluids are doubtlessly the cause of the slight and perfectly harmless trembling of the earth's surface, which has often continued several days (as in 1816, at Scaccia, in Sicily, before the volcanic elevation of the island of Julia), as well as of the terrific explosion accompanied by loud noise. The focus of this destructive agent, the seat of the moving force, lies far below the earth's surface; but we know as little of the extent of this depth as we know of the chemical nature of these vapors that are so highly compressed. At the edges of two craters, Vesuvius, and the towering rock which projects beyond the great abyss of Pichincha, near Quito, I have felt periodic and very regular shocks of earthquakes, on each occasion from 20 to 30 seconds before the burning scoria or gases were erupted. The intensity of the shocks was increased in proportion to the time intervening between them, and, consequently, to the length of time in which the vapors were accumulating. This simple fact, which has been attested by the evidence of so many travelers, furnishes us with a general solution of the phenomenon, in showing that active volcanoes are to be considered as safety valves for the immediate neighborhood. The danger of earthquakes increases when the openings of the volcano are closed and deprived of free communication with the atmosphere; but the destruction of Lisbon, of Caracas, of Lima, of Cashmir in 1554,[17] and of so many cities of Calabria, Syria, and Asia Minor, shows us, on the whole, that the force of the shock is not the greatest in the neighborhood of active volcanoes.

As the impeded activity of the volcano acts upon the shocks of the earth's surface, so do the latter react on the volcanic phenomena. Openings of fissures favor the rising of cones of eruption, and the processes which take place in these cones, by forming a free communication with the

[17]On the frequency of earthquakes in Cashmir, see Troyers German translation of the ancient Radjataringini, vol. ii., p. 297, and Carl Hiigel, Reisen, bd. ii., 8. 184.

atmosphere. A column of smoke, which had been observed to rise for months together from the volcano of Pasto, in South America, suddenly disappeared when, on the 4th of February, 1797, the province of Quito, situated at a distance of 192 miles to the south, suffered from the great earthquake of Riobamba. After the earth had continued to tremble for some time throughout the whole of Syria, in the Cyclades, and in Eubeea, the shocks suddenly ceased on the eruption of a stream of hot mud on the Lelantine plains near Chalcis.[18] The intelligent geographer of Amasea, to whom we are indebted for the notice of this circumstance, further re-

[18]Strabo, lib. i., p. 100, Casaub. That the expression 77/00 diantpov morauéy does not mean erupted mud, but lava, is obvious from a passage in Strabo, lib. vi., p. 412. Compare Walter, in his Abnakme der Vulkanischen Thatigheit in Historischen Zeiten (On the Decrease of Vol- canic Activity during Historical Times), 1844, s. 25.

marks: “Since the craters of Etna have been opened, which yield a passage to the escape of fire, and since burning masses and water have been ejected, the country near the sea-shore has not been so much shaken as at the time previous to the separation of Sicily from Lower Italy, when all communications with the external surface were closed.”

We thus recognize in earthquakes the existence of a volcanic force, which, although everywhere manifested, and as generally diffused as the internal heat of our planet, attains but rarely, and then only at separate points, sufficient intensity to exhibit the phenomenon of eruptions. The formation of veins, that is to say, the filling up of fissures with crystalline masses bursting forth from the interior (as basalt, melaphyre, and greenstone), gradually disturbs the free inter-communication of elastic vapors. This tension acts in three different ways, either in causing disruptions, or sudden and retroversed elevations, or, finally, as was first observed in a great part of Sweden, in producing changes in the relative level of the sea and land, which, although continuous, are only appreciable at intervals of long period.

Before we leave the important phenomena which we have considered, not so much in their individual characteristics as in their general physical and geognostical relations, I would advert to the deep and peculiar impression left on the mind by the first earthquake which we experience, even where it is not attended by any subterranean noise.[19] This impression is not,

[19] [Dr. Tschudi, in his interesting work, Travels in Peru, translated from the German by Thomasina Ross, p. 170, 1847, describes

in my opinion, the result of a recollection of those fearful pictures of devastation presented to our imaginations by the historical narratives of the past, but - is rather due to the sudden revelation of the delusive nature of the inherent faith by which we had clung to a belief in the immobility of the solid parts of the earth. We are accustomed from early childhood to draw a contrast between the mobility of water and the immobility of the soil on which

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strikingly the effect of an earthquake upon the native and upon the stranger. "No familiarity with the phenomenon can blunt this feeling. The inhabitant of Lima, who from childhood has frequently witnessed these convulsions of nature, is roused from his sleep by the shock, and rushes from his apartment with the cry of Misericordia! The foreigner from the north of Europe, who knows nothing of earthquakes but by description, waits with impatience to feel the movement of the earth, and longs to hear with his own ear the subterranean sounds which he has hitherto considered fabulous. With levity he treats the apprehension of a coming convulsion, and laughs at the fears of the natives; but, as soon as his wish is gratified, he is terror-stricken, and is involuntarily prompted to seek safety in flight."] – Tr.

we tread; and this feeling is confirmed by the evidence of our senses. When, therefore, we suddenly feel the ground move beneath us, a mysterious and natural force, with which we are previously unacquainted, is revealed to us as an active disturbance of stability. A moment destroys the illusion of a whole life; our deceptive faith in the repose of nature vanishes, and we feel transported, as it were, into a realm of unknown destructive forces. Every sound - the faintest motion in the air - arrests our attention, and we no longer trust the ground on which we stand. Animals, especially dogs and swine, participate in the same anxious disquietude; and even the crocodiles of the Orinoco, which are at other times as dumb as our little lizards, leave the trembling bed of the river and run with loud cries into the adjacent forests.

To man, the earthquake conveys an idea of some universal and unlimited danger. We may flee from the crater of a volcano in active eruption or from the dwelling whose destruction is threatened by the approach of the lava stream, but in an earthquake, direct our flight whithersoever we will, we still feel as if we trod upon the very focus of destruction. This condition of the mind is not of long duration, although it takes its origin in the deepest recesses of our nature, and when a series of faint shocks succeed one another, the inhabitants of the country soon lose every trace of fear. On the coasts of Peru, where rain and hail are unknown, no less than the rolling thunder and the flashing lightning, these luminous explosions of the atmosphere are replaced by the subterranean noises which accompany earthquakes.[20] Long habit, and the very prevalent opinion that dangerous shocks are only to be apprehended two or three times in the course of a century, cause faint oscillations of the soil to be regarded in Lima with scarcely more attention than a hail storm in the temperate zone.

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[20][“Along the whole coast of Peru, the atmosphere is almost uniformly in a state of repose. It is not illuminated by the lightning’s flash, or disturbed by the roar of the thunder; no deluges of rain, no fierce hurricanes, destroy the fruits of the fields, and with them the hopes of the husbandman. But the mildness of the elements above ground is frightfully counterbalanced by their subterranean fury. Lima is frequently visited by earthquakes, and several times the city has been reduced to a mass of ruins. On average, forty-five shocks may be counted on in the year. Most of them occur in the latter part of October, November, December, January, May, and June. Experience gives reason to expect the visitation of two desolating earthquakes in a century. The period between the two is from forty to sixty years. The most considerable catastrophes experienced in Lima since Europeans have visited the west coast of South America happened in the years 1586, 1630, 1687, 1713, 1746, 1806. There is reason to fear that in the course of a few years this city may be the prey of another such visitation.” —Tschudi, op. cit.] – Tr.

Chapter 22

Gaseous Emanations

Having thus taken a general view of the activity – the inner life, as it were – of the Earth, in respect to its internal heat, its electro-magnetic tension, its emanation of light at the poles, and its irregularly-recurring phenomena of motion, we will now proceed to the consideration of the material products, the chemical changes in the earth's surface, and the composition of the atmosphere, which are all dependent on planetary vital activity. We see issue from the ground steam and gaseous carbonic acid, almost always free from the admixture of nitrogen ;[1] carbureted hydrogen gas, which has been used in the Chinese province Sse-tschuant[2] for several thousand years, and recently in the village of Fredonia, in the State of New York, United States, in cooking and for illumination ; sulphureted hydrogen gas and sulphurous vapors; and, more rarely,[3] sul-

[1]Bischof's comprehensive work, Warmelehre des inneren Erdkérpers.

[2]On the Artesian fire-springs (Ho-tsing) in China, and the ancient use of portable gas (in bamboo canes) in the city of Khiung-tsheu, see Klaproth, in my Asie Genérale, t. iii., p. 519-530.

[3]Boussingault (Annales de Chimie, t. lii., p. 181) observed no evolution of hydrochloric acid from the volcanoes of New Granada, while Monticelli found it in enormous quantity in the eruption of

phurous and hydrochloric acids.[4] Such effusions from the fissures of the earth not only occur in the districta of still burning or long-extinguished volcanoes, but they may likewise be observed occasionally in districts where neither trachyte nor any other volcanic rocks are exposed on the earth's surface. In the chain of Quindiu I

Vesuvius in 1813.

[4][Of the gaseous compounds of sulphur, one, sulphurous acid, appears to predominate chiefly in volcanoes possessing a certain degree of activity, while the other, sulphureted hydrogen, has been most frequently perceived among those in dormant condition. The occurrence of abundant exhalations of sulphuric acid, which have been hitherto noticed chiefly in extinct volcanoes, as, for instance, in a stream issuing from that of Puracé, between Bogota and Quito, from extinct volcanoes in Java, is satisfactorily explained in a recent paper by M. Dumas, Annales de Chimie, Dec., 1846. He shows that when sulphureted hydrogen, at a temperature above 100° Fahr., and still better when near 190°, comes in contact with certain porous bodies, a catalytic action is set up, by which water, sulphuric acid, and sulphur are produced. Hence probably the vast deposits of "sulphur, associated with sulphates of lime and strontian, which are met with in the western parts of Sicily.] – Tr.

have seen sulphur deposited in mica slate from warm sulphurous vapor at an elevation of 6832 feet[5] above the level of the sea, while the same species of rock, which was formerly regarded as primitive, contains, in the Cerro Cuello, near Tisean, south of Quito, an immense deposit of sulphur imbedded in pure quartz.

Exhalations of carbonic acid (mofettes) are even in our days to be considered as the most important of all gaseous emanations, with respect to their number and the amount of their effusion. We see in Germany, in the deep valleys of the Eifel, in the neighborhood of the Lake of Laach,[6] in the crater-like valley of the Wehr and in Western Bohemia, exhala-

[5]Humboldt, Recueil d@' Observ. Astronomiques, t. i., p. 311 (Nivellement Barométrique de la Cordillére des Andes, No. 206).

[6][The Lake of Laach, in the district of the Eifel, is an expanse of water two miles in circumference. The thickness of the vegetation on the sides of its crater-like basin renders it difficult to discover the

tions of carbonic acid gas manifest themselves as the last efforts of volcanic activity in or near the foci of an earlier world. In those earlier periods, when a higher terrestrial temperature existed, and when a great number of fissures still remained unfilled, the processes we have described acted more powerfully, and carbonic acid and hot steam were mixed in larger quantities in the atmosphere, from whence it follows, as Adolph Brongniart

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nature of the subjacent rock, but it is probably composed of black cellular augitic lava. The sides of the crater present numerous loose masses, which appear to have been ejected, and consist of glassy feldspar, ice-spar, sodalite, hauyne, spinellane, and leucite. The resemblance between these products and the masses formerly ejected from Vesuvius is most remarkable. (Daubeney On Volcanoes, p. 81.) Dr. Hibbert regards the Lake of Laach as formed in the first instance by a crack caused by the cooling of the crust of the earth, which was widened afterward into a circular cavity by the expansive force of elastic vapors. See History of the Extinct Volcanoes of the Basin of Newwied, 1832.] – Tr.

has ingeniously shown,[7] that the primitive vegetable world must have exhibited almost everywhere, and independently of geographical position, the most luxurious abundance and the fullest development of organism. In these constantly warm and damp atmospheric strata, saturated with carbonic acid, vegetation must have attained a degree of vital activity, and derived the superabundance of nutrition necessary to furnish materials for the formation of the beds of lignite (coal), constituting the inexhaustible means on which are based the physical power and prosperity of nations. Such masses are distributed in basins over certain parts of Europe, occurring in large quantities in the British Islands, in Belgium, in France, in

[7] Adolph Brongniart, in the Annales des Sciences Naturelles, t. xv. p- 225.

the provinces of the Lower Rhine, and in Upper Silesia. At the same primitive period of universal volcanic activity, those enormous quantities of carbon must also have escaped from the earth which are contained in limestone rocks, and which, if separated from oxygen and reduced to a solid form, would constitute about the eighth part of the absolute bulk of these mountain masses.[8] That portion of the carbon which was not taken up by alkaline earths, but remained mixed with the atmosphere, as carbonic acid, was gradually consumed by the vegetation of the earlier stages of the world, so that the atmosphere, after being purified by the processes of vegetable life, only retained the small quantity which it now possesses, and which is not injurious to the present

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[8] Bischof, op. cit., s. 324, Anm. 2.

organization of animal life. Abundant eruptions of sulphurous vapor have occasioned the destruction of the species of mollusca and fish which inhabited the inland waters of the earlier world, and have given rise to the formation of the contorted beds of gypsum, which have doubtless been frequently affected by shocks of earthquakes.

Gaseous and liquid fluids, mud, and molten earths, ejected from the craters of volcanoes, which are themselves only a kind of intermittent springs, rise from the earth under precisely analogous physical relations.[9] All these substances owe their temperature and their chemical character to the place of their origin. The mean temperature of aqueous springs is less than that of the air at the point whence they

[9] Humboldt, Asie Centrale, t. i., p. 43.

emerge, if the water flow from a height; but their heat increases with the depth of the strata with which they are in contact at their origin. We have already spoken of the numerical law regulating this increase. The blending of waters that have come from the height of a mountain with those that have sprung from the depths of the earth, render it difficult to determine the position of the *isogeothermal lines*[10] (lines of equal internal terrestrial temperature), when this determination is to be made from the temperature of flowing springs. Such, at any rate, is the result I have arrived at from my own observations and those of

[10]On the theory of isogeothermal (chthonisothermal) lines, consult the ingenious labors of Kupifer, in Pogg., Annalen, bd xv., 8. 184, and bd. xxxii., s. 270, in the Voyage dans lOural, p. 382398, and in theEdinburgh Journal of Science, New Series, vol. iv., p. 355. See, also,Kamtz, Lehrb. der Meteor., bd. ii., s. 217; and, on the ascent of thechthonisothermal lines in mountainous districts, Bischof, s. 174198.

my fellowtravelers in Northern Asia. The temperature of springs, which has become the subject of such continuous physical investigation during the last half century, depends, like the elevation of the line of perpetual snow, on very many simultaneous and deeply involved causes. It is a function of the temperature of the stratum in which they take their rise, of the specific heat of the soil, and of the quantity and temperature of the meteoric water,[11] which is itself different from the temperature of the lower strata of the atmosphere, according to the different modes of its origin in rain, snow, or hail.[12]

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[11]Leop. v. Buch, in Pogg., Annalen, bd. xii., 8. 405.

[12]On the temperature of the drops of rain in Cumana, which fell to72, when the temperature of the air shortly before had been 86 and83, and during the rain sank to 74, see my Relat. Hist., t. ii., p. 22.The raindrops, while falling, change the normal temperature they originally possessed, which depends on the height of the clouds fromwhich they fell, and their heating on their upper surface by the

Cold springs can only indicate the mean atmospheric temperature when they are

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solarrays. The raindrops, on their first production, have a higher temperature than the surrounding medium in the superior strata of our atmosphere, in consequence of the liberation of their latent heat; and theycontinue to rise in temperature, since, in falling through lower andwarmer strata, vapor is precipitated on them, and they thus increase insize (Bischof, Warmelehre des inneren Erdkérpers, 8.73); but this additional heating is compensated for by evaporation. The cooling of theair by rain (putting out of the question what probably belongs to theelectric process in storms) is effected by the drops, which are themselves of lower temperature, in consequence of the cold situation inwhich they were formed, and bring down with them a portion of thehigher colder air, and which finally, by moistening the ground, giverise to evaporation. These are the ordinary relations of the phenomenon. When, as occasionally happens, the raindrops are warmer thanthe lower strata of the atmosphere (Humboldt, Rel. Hist., t. iii., p.513), the cause must probably ta sought in higher warmer currents, orin a higher temperature of widelyextended and not very thick clouds,from the action of the suns rays. How, moreover, the phenomenon ofsupplementary rainbows, which are explained by the interference oflight, is connected with the original and increasing size of the fallingdrops, and how an optical phenomenon, if we know how to observe itaccurately, may enlighten us regarding a meteorological process, according to diversity of zone, has been shown, with much talent and in.genuity, by Arago, in the Annuaire for 1836, p. 300.

unmixed with the waters rising from great depths, or descending from considerable mountain elevations, and when they have passed through a long course at a depth from the surface of the earth which is equal in our latitudes to 40 or 60 feet, and, according to Boussingault, to about one foot in the equinoctial regions;[13] these being the depths at which the invariability of the temperature begins in the temperate and torrid zones, that is to say, the depths

[13] The profound investigations of Boussingault fully convince me that in the tropics, the temperature of the ground, at a very slight depth, exactly corresponds with the mean temperature of the air. The following instances are sufficient to illustrate this fact. See Table 22.1. The doubts about the temperature of the earth within the tropics, of which I am probably, in some degree, the cause, by my observations on the Cave of Caripe (Cueva del Guacharo), Rel. Hist., t. iii., p. 191-196), are resolved by the consideration that I compared the presumed mean temperature of the air of the convent of Caripe, 65.93, not with the temperature of the air of the cave, 65.6, but with the temperature of the subterranean stream, 62.93, although I observed (Rel. Hist., t. iii., p. 146 and 194) that mountain water from a great height might probably be mixed with the water of the cave.

at which hourly, diurnal, and monthly changes of heat in the atmosphere cease to be perceived.

Table 22.1: Temperature measurements at various stations within tropical zones.

Stations within Tropical Zones.	**Temperature at 1 French foot (1.006 of the English foot) below the earth's surface.**	**Mean Temperature of the air.**	**Height, in English feet, above the level of the sea.**
Guayaquil	78.8	78.1	0
Anserma Nuevo	74.6	74.8	3444
Zupia	70.7	70.7	4018
Popayan	64.7	65.6	5929
Quito	59.9	59.9	9559

Chapter 23

Hot Springs

Hot springs issue from the most various kinds of rocks. The hottest permanent springs that have hitherto been observed are, as my own researches confirm, at a distance from all volcanoes. I will here advert to a notice in my journal of the Aguas Calientes de las Trincheras, in

South America, between Porto Cabello and Nueva Valencia, and the Aguas de Comangillas, in the Mexican territory, near Guanaxuato; the former of these, which issued from granite, had a temperature of 1945; the latter, issuing from basalt, 2055. The depth of the source from whence the water flowed with this temperature, judging from what we know of the law of the increase of heat in the interior of the earth, was probably 7140 feet, or above two miles. If the universally diffused terrestrial heat be the cause of thermal springs, as of active volcanoes, the rocks can only exert an influence by their different capacities for heat and by their conducting powers. The hottest of all permanent springs (between 203 and 209) are likewise, in a most remarkable degree, the purest, and such as hold in solution the smallest quantity of mineral substances. Their temperature appears, on the whole, to be less constant than that of springs between 122 and 165, which in Europe, at least, have maintained, in a most remarkable manner, their invariability of heat and mineral contents during the last fifty or sixty years, a period in which thermometrical measurements and chemical analyses have been applied with increased exactness. Boussingault found in 1823 that the thermal springs of Las Trincheras had risen 12 during the twenty-three years that had intervened since my travels in 1800.[1]

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[1]Boussingault, in the Annals de Chimie, t. lii., p.181. The springof Chaudes Aigues, in Auvergne, is only 1769. It is also to be observed, that while the Aguas Calientes de las Trincheras, south of Porto Cabello (Venezuela), springing from granite cleft in regular beds, andfar from all volcanoes, have a temperature of fully 20696, all the springswhich rise in the vicinity of still active volcanoes (Pasto, Cotopaxi, andTunguragua) have a temperature of only 97°-130°.

This calmly flowing spring is therefore now nearly 12 hotter than the intermittent fountains of the Geyser and the Strokr, whose temperature has recently been most carefully determined by Krug of Nidda. A very striking proof of the origin of hot springs by the sinking of cold meteoric water into the earth, and by its contact with a volcanic focus, is afforded by the volcano of Jorulla in Mexico, which was unknown before my American journey. When, in September, 1759, Jorullo was suddenly elevated into a mountain 1183 feet above the level of the surrounding plain, two small rivers, the Rio de Cuitimba and Rio de San Pedro, disappeared, and sometime afterward burst forth again, during violent shocks of an earthquake, as hot springs, whose temperature I found in 1803 to be 186°.4.

The springs in Greece still evidently flow at the same places as in the times of Hellenic antiquity. The spring of Hrasinos, two hours journey to the south of Argos, on the declivity of Chaon, is mentioned by Herodotus. At Delphi we still see Cassotis (now the springs of St. Nicholas) rising south of the Lesche, and flowing beneath the Temple of Apollo; Castalia, at the foot of Phedriade; Pirene, near AcroCorinth; and the hot baths of Aidipsus, in Eubea, in which Sulla bathed during the Mithridatic war.[2] I advert with pleasure to these

[2]Cassotis (the spring of St. Nicholas) and Castalia, at the Phedriade, mentioned in Pausanias, x., 24, 25, and x., 8,9; Pirene (Acro-Corinth) in Strabo, p. 379; the spring of Erasinos, at Mount Chaon, south of Argos, in Herod., vi., 67, and Pausanias, ii., 24, 7; the springs of Adipsusin Eubeea, some of which have a temperature of 88, while in others itranges between 144 and 1679, in Strabo, p. 60 and 447, and Atheneus,ij., 3,73; the hot springs of Thermopyle, at the foot of Eta, with atemperature of 149. All from manuscript notes by Professor Curtius,the learned companion of Otfried Miller.

facts, as they show us that, even in a country subject to frequent and violent shocks of earthquakes, the interior of our planet has retained for upward of 2000 years its ancient configuration in reference to the course of the open fissures that yield a passage to these waters. The Pontaine jaillissante of Lillers, in the Department des Pas de Calais, which was bored as early as the year 1126, still rises to the same height and yields the same quantity of water; and, as another instance, I may mention that the admirable geographer of the Caramanian coast, Captain Beaufort, saw in the district of Phaselis the same flame fed by emissions of inflammable gas which was described by Pliny as the flame of the Lycian Chimera.[3]

[3]Pliny, ii., 106; Seneca, Epist., 79, 3, ed. Ruhkopf (Beaufort, Survey of the Coast of Karamania, 1820, art. Yanar, near Deliktasch, theancient Phaselis, p. 24).. See, also, Ctesias, Fragm., cap. 10 p.

The observation made by Arago in 1821, thatthe deepestArtesian wells are the warmest,[4] threw great light on the origin of thermal springs, and on the establishment of the lawthat terrestrial heat increases with increasing depth. It isaremarkable fact, which has but recently been noticed, that atthe close of the third century, St. Patricius,[5] probably Bishopof

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250,ed. Bahr; Strabo, lib. xiv,, p. 666, Casaub.;

["Not far from the Deliktash, on the side of 2 mountain, is the perpetual fire described by Captain Beaufort. The travelers found it asbrilliant as ever, and even somewhat increased ; for, besides the largeflame in the corner of the ruins described by Beaufort, there were smalljets issuing from crevices in the side of the craterlike cavity five orsix feet deep. At the bottom was a shallow pool of sulphureous andturbid water, regarded by the Turks as a sovereign remedy for all skincomplaints. The soot deposited from the flames was regarded as efficacious for sore eyelids, and valued as a dye for the eyebrows." See the highly interesting and accurate work, Travels in Lycia, by Lieut.Spratt and Professor E. Forbes.] – Tr.

[4] Arago, in the Annuaire pour 1835, p. 234.

[5] Acta 8. Patricti, p. 555, ed. Ruinart, t. ii., p. 385, Mazochi. Dareau de la Malle was the first to draw attention to this remarkable

Pertusa, was led to adopt very correct views regarding thephenomenon of the hot springs at Carthage. On being asked- what was the cause of boiling water bursting from the earth,he replied, Fire is nourished in the clouds and in the interior of the earth, as Etna and other mountains near Naples mayteach you. The subterranean waters rise as if through siphons. The cause of hot springs is this waters which aremore remote from the subterranean fire are colder, while thosewhich rise nearer the fire are heated by it, and bring withthem to the surface which we inhabit an insupportable degreeof heat.

As earthquakes are often accompanied by eruptions of waterand vapors, we recognize in the Salses,[6] or small mud

passage in the Recherches sur la Topographi de Carthage, 1835, p. 276(See, also, Seneca, Nat. Quest., iii., 24.)

[6][True volcanoes, as we have seen, generate sulphureted hydro-

volcanoes, a transition from the changing phenomena presentedby these eruptions of vapor and thermal springs to the morepowerful and awful activity of the streams of lava that flowfrom volceanic mountains. If we consider these mountains assprings of molten earths producing voleanic rocks, we must remember that thermal waters, wheu impregnated with carbonicacid and sulphurous gases, are continually forming horizontally ranged strata of limestone (travertine) or conical elevations, as in Northern Africa (in Algeria), and in the Banosof Caxamarca, on the western declivity of the Peruvian Cordilleras. The travertine

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genand muriatic acid, upheave tracts of land, and emit streams of meltedfeldspathic materials ; salses, on the contrary, disengage little else butcarbureted hydrogen, together with bitumen and other products of thedistillation of coal, and pour forth no other torrents except of mud, or argillaceous materials mixed up with water. Daubeney, op cit., p540.] – Tr.

of Van Diemens Land (near HobartTown) contains, according to Charles Darwin, remains of avegetation that no longer exists. Lava and travertine, whichare constantly forming before our eyes, present us with thetwo extremes of geognostic relations.

Chapter 24

Salses

SALSES deserve more attention than they have hitherto received from geognosists. Their grandeur has been overlooked because of the two conditions to which they are subject; it is only the more peaceful state, in which they may continue for centuries, which has generally been described. Their origin is, however, accompanied by earthquakes, subterranean thunder, the elevation of a whole district, and lofty emissions of flame of short duration. When the mud volcano of Jokmali began to form on the 27th of November, 1827, in the peninsula of Abscheron, on the Caspian Sea, east of Baku, the flames flashed up to an extraordinary height for three hours, while during the next twenty hours they scarcely rose three feet above the crater, from which mud was ejected. Near the village of Baklichli, west of Baku, the flames rose so high that they could be seen at a distance of twenty-four miles. Enormous masses of rock were torn up and scattered around. Similar masses may be seen around the now inactive mud volcano of Monte Zibio, near Sassuolo, in Northern Italy. The secondary condition of repose has been maintained for upward of fifteen centuries in the mud volcanoes of Girgenti, the Macatubi, in Sicily, which have been described by the ancients. These salses consist of many contiguous conical hills, from eight to ten, or even thirty feet in height, subject to variations of elevation as well as of form. Streams of argillaceous mud, attended by a periodic development of gas, flow from the small basins at the summits, which are filled with water; the mud, although usually cold, is sometimes at a high temperature, as at Damak, in the province of Samarang, in the island of Java. The gases that are developed with loud noise differ in their nature, consisting, for instance, of hydrogen mixed with naphtha, or of carbonic acid, or, as Parrot and myself have shown (in the peninsula of Taman, and in the Volcancitos de Turbaco, in South America), of almost pure nitrogen.[1]

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[1]Humboldt, Rel. Hist., t. iii., p. 562567 ; Asie Centrale, t.i., p. 43;t. ii., p. 505515; Vues des Cordilléres, pl. xli. Regarding the Macalubi (the Arabic Makhiub, the overthrown or inverted, from the wordKhalaba), and on the Earth ejecting fluid earth, see Solinus, cap. 5idem ager Agrigentinus eructat limosas scaturigenes, et ut ven funtium sufficiunt rivis subministrandis, ita in hac Sicili parte solo nunsquam deficiente, eterna rejectatione terram terra evomit.

Chapter 25

Volcanoes

MUD volcanoes, after the first violent explosion of fire, which is not, perhaps, in an equal degree common to all, present to the spectator an image of the uninterrupted but weak activity of the interior of our planet. The communication with the deep strata in which a high temperature prevails is soon closed, and the coldness of the mud emissions of the salses seems to indicate that the seat of the phenomenon cannot be far removed from the surface during their ordinary condition. The reaction of the interior of the earth on its external surface is exhibited with totally different force in true volcanoes or igneous mountains, at points of the earth in which a permanent, or, at least, continually renewed connection with the volcanic force is manifested. We must here carefully distinguish between the more or less intensely developed volcanic phenomena, as, for instance, between earthquakes, thermal, aqueous, and gaseous springs, mud volcanoes, and the appearance of bell-formed or dome-shaped trachytic rocks without openings; the opening of these rocks, or of the elevated beds of basalt, as craters of elevation; and, lastly, the elevation of a permanent volcano in the crater of elevation, or among the debris of its earlier formation. At different periods, and in different degrees of activity and force, the permanent volcanoes emit steam, acids, luminous scoriae, or, when the resistance can be overcome, narrow, band-like streams of molten earths. Elastic vapors sometimes elevate either separate portions of the earth's crust into dome-shaped unopened masses of feldspathic trachyte and dolerite (as in Puy de Dome and Chimborazo), in consequence of some great or local manifestation of force in the interior of our planet, or the upheaved strata are broken through and curved in such a manner as to form a steep rocky ledge on the opposite inner side, which then constitutes the enclosure of a crater of elevation. If this rocky ledge has been uplifted from the bottom of the sea, which is by no means always the case, it determines the whole physiognomy and form of the island. In this manner has arisen the circular form of Palma, which has been described with such admirable accuracy by Leopold von Buch, and that of Nisyros,[1] in the Aegean Sea. Sometimes half of the annular ledge has been destroyed, and in the bay formed by the encroachment of the sea corallines have built their cellular habitations. Even on continents craters of elevation are often filled with water and embellish in a peculiar manner the character of the landscape. Their origin is not connected with any determined species of rock; they break out in basalt, trachyte, leucitic porphyry (somma), or in doleritic mixtures of augite and labradorite; and hence arise the different nature and ex-

[1]See the interesting little map of the island of Nisyros, in Ross's Reisen auf den Griechischen Inseln, bd. ii., 1843, 8. 69.

ternal conformation of these enclosures of craters. No phenomena of eruptions are manifested in such craters, as they open no permanent channel of communication with the interior, and it is but seldom that we meet with traces of volcanic activity either in the neighborhood or in the interior of these craters. The force which was able to produce so important an action must have been long accumulating in the interior before it could overpower the resistance of the mass pressing upon it; it sometimes, for instance, on the origin of new islands, will raise granular rocks and conglomerated masses (strata of tufa filled with marine plants) above the surface of the sea. The compressed vapors escape through the crater of elevation, but a large mass soon falls back and closes the opening, which had been only formed by these manifestations of force. No volcano can, therefore, be produced.[2]

A volcano, properly so called, exists only where a permanent connection is established between the interior of the earth and the atmosphere, and the reaction of the interior on the surface then continues during long periods of time. It may be interrupted for centuries, as in the case of Vesuvius, Fisove,[3] and then

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[2]Leopold von Buch, Phys. Beschreibung der Canarischen Inseln, s.326; and his Memoir über Erhebungscratere und Vulcane, in Poggend., Annal., bd. xxxvii., s. 169.

In his remarks on the separation of Sicily from Calabria, Strabo gives an excellent description of the two modes in which islands are formed. Some islands, he observes (lib. vi., p. 258, ed. Casaub.), are fragments of the continent, others have arisen from the sea, as even at the present time is known to happen; for the islands of the great ocean, lying far from the mainland, have probably been raised from its depths, while, on the other hand, those near promontories appear (according to reason) to have been separated from the continent.

[3]Ocre Fisove (Mons Vesuvius) in the Umbrian language. (Lassen, Deutung der Eugubinischen Tafeln in Rhein. Museum, 1832, s. 387.) The word ochre is very probably genuine Umbrian,

manifest itself with renewed activity. In the time of Nero, men were disposed to rank AStna among the volcanic mountains which were gradually becoming extinct;[4]

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and means, according to Festus, mountain. Atna would be a burning and shining mountain, if Voss is correct in stating that Airvy is a Hellenic sound, and is connected with aifw and atcvo; but the intelligent writer Parthey doubts this Hellenic origin on etymological grounds, and also because tna was by no means regarded as a luminous beacon for ships or wanderers, in the same manner as thé ever-travailing Stromboli (Strongyle), to which Homer seems to refer in the Odyssey (xii., 68, 202, and 219), and its geographical position was not so well determined. I suspect that tna would be found to be a Sicilian word, if we had any fragmentary materials to refer to. According to Diodorus (v., 6), the Sicani, or aborigines preceding the Sicilians, were compelled to fly to the western part of the island, in consequence of successive eruptions extending over many years. The most ancient eruption of Mount Atna on record is that mentioned by Pindar and Aschylus, as occurring under Hiero, in the second year of the 75th Olympiad. It is probable that Hesiod was aware of the devastating eruptions of Htna before the period of Greek immigration. There is, however, some doubt regarding the word Airvy in the text of Hesiod, a subject into which I have entered at some length in another place. (Humboldt, Examen Critdele Géogr., t.i., p. 168.)

[4]Seneca, Epist., 79. lian, Var. Hist., viii., 11

and subsequently Aclian even maintained that mariners could no longer see the sinking summit of the mountain from so great a distance at sea. Where these evidences these old scaffolding of eruption, I might almost say still exist, the volcano rises from a crater of elevation, while a high rocky wall surrounds, like an amphitheater, the isolated conical mount, and forms around it a kind of casing of highly elevated strata. Occasionally not a trace of this enclosure is visible, and the volcano, which is not always conical, rises immediately from the neighboring plateau in an elongated form, as in the case of Pichincha,[5] at the foot of

[5] [This mountain contains two funnel-shaped craters, apparently resulting from two sets of eruptions the western nearly circular, and having i in its center a cone of eruption, from the summit and sides of which are no less than seventy vents, some in activity and others extinct. It is probable that the larger number of the vents were produced at periods anterior to history. Daubeney, op. cit., p. 488. J 7] – Tr.

which lies the city of Quito.

As the nature of rocks, or the mixture (grouping) of simple minerals into granite, gneiss, and mica slate, or into trachyte, basalt, and dolorite, is independent of existing climates, and is the same under the most varied latitudes of the earth, so also we find everywhere in inorganic nature that the same laws of configuration regulate the reciprocal superposition of the strata of the earth's crust, cause them to penetrate one another in the form of veins, and elevate them by the agency of elastic forces. This constant recurrence of the same phenomena is most strikingly manifested in volcanoes. When the mariner, amid the islands of some distant archipelago, is no longer guided by the light of the same stars with which he had been familiar in his native latitude, and sees himself surrounded by palms and other forms of exotic vegetation, he still can trace, reflected in the individual characteristics of the landscape, the forms of Vesuvius, the dome-shaped summits of Auvergne, the craters of elevation in the Canaries and Azores, or the fissures of eruption in Iceland. A glance at the satellite of our planet will impart a wider generalization to this analogy of configuration. By means of the charts that have been drawn in accordance with the observations made with large telescopes, we may recognize in the moon, where water and air are both absent, vast craters of elevation surrounding or supporting conical mountains, thus affording incontrovertible evidence of the effects produced by the reaction of the interior on the surface, favored by the influence of a feebler force of gravitation.

Although volcanoes are justly termed in many languages fire-emitting mountains, mountains of this kind are not formed by the gradual accumulation of ejected currents of lava, but their origin seems rather to be a general consequence of the sudden elevation of soft masses of trachyte or labradorite augite. The amount of the elevating force is manifested by the elevation of the volcano, which varies from the inconsiderable height of a hill (as the volcano of Cosima, one of the Japanese Kurile islands) to that of a cone above 19,000 feet in height. It has appeared to me that relations of height have a great influence on the occurrence of eruptions, which are more frequent in low than in elevated volcanoes. I might instance the series presented by the following mountains: Stromboli, 2318 feet; Guacamayo, in the province of Quixos, from which detonations are heard almost daily (I have myself often heard them at Chillo, near Quito, a distance of eighty-eight miles); Vesuvius, 3876 feet; Aitna, 10,871 feet; the Peak of Teneriffe, 12,175 feet; and Cotopaxi, 19,069 feet. If the focus of these volcanoes be at an equal depth below the surface, a greater force must be required where the fused masses have to be raised to an elevation six or eight times greater than that of the lower eminences. While the volcano Stromboli (Strongyle) has been incessantly active since the Homeric ages, and has served as a beacon light to guide the mariner in the Tyrrhenian Sea, loftier volcanoes have been characterized by long intervals of quiet. Thus we see that a whole century often intervenes between the eruptions of most of the colossi which crown the summits of the Cordilleras of the Andes. Where we meet with exceptions to this law, to which I long since drew attention, they must depend upon the circumstance that the connections between the volcanic foci and the crater of eruption cannot be considered as equally permanent in the case of all volcanoes. The channel of communication may be closed for a time in the case of the lower ones, so that they less frequently come to a state of eruption, although they do not, on that account, approach more nearly to their final extinction.

These relations between the absolute height and the frequency of volcanic eruptions, as far as they are externally perceptible, are intimately connected with the consideration of the local conditions under which lava currents are erupted. Eruptions from the crater are very unusual in many mountains, generally occurring from lateral fissures (as was observed in the case of Aitna, in the sixteenth century, by the celebrated historian Bembo, when a youth[6]), wherever the sides of the upheaved mountain were least able, from their configuration and position, to offer any resistance. Cones of eruption are sometimes uplifted on these fissures; the larger ones, which are erroneously termed new volcanoes, are ranged together in a line marking the direction of a fissure, which is soon reclosed, while the smaller ones are grouped together, covering a whole district with their domelike or hiveshaped forms. 'To the latter be-

[6]Petri Bembi Opuscula (Aitna Dialogus), Basil, 1556, p. 63 Quicquid in tne matris utero coalescit, nunquam exit ex cratere superiore, quod vel eo inscondere gravis materia non queat, vel, quia inferius aliaspiramenta sunt, non fitopus. Despumant flammis urgentibus ignei riv.pigro fluxu totas delambentes plagas, et in lapidem indurescunt.

long the hornitos de Jorullo,[7] the cone of Vesuvius erupted in October, 1822, that of Awatscha, according to Postels, and those of the lava field mentioned by Erman, near the Baidar Mountains, in the peninsula of Kamtschatka.

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When volcanoes are not isolated in a plain, but surrounded,as in the double chain of the Andes of Quito, by a tablelandhaving an elevation from nine to thirteen thousand feet, thiscircumstance may probably explain the cause why no lavastreams are formed[8] during the most

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[7]See my drawing of the volcano of Jorullo, of its hornitos, and of the uplifted malpays, in my Vues de Cordillères, pl. xliii., p. 239.

[Burckhardt states that during the twentyfour years that have intervened since Baron Humboldts visit to Jorullo, the hornitos have either wholly disappeared or completely changed their forms. See Aufenthalt und Reisen in Mexico in 1825 und 1834.] – Tr.

[8]Humboldt, Essai sur la Géogr. des Plantes et Tableau Phys. des Régions Equinoxiales, 1807, p. 130, and Essai Géogn. sur le Gise-

dreadful eruption of ignited scoriz accompanied by detonations heard at a distanceof more than a hundred miles. Such are the volcanoes of Popayan, those of the elevated plateau of Los Pastos and of theAndes of Quito, with the exception, perhaps, in the case ofthe latter, of the voleano of Antisana. The height of the coneof cinders, and the size and form of the crater, are elementsof configuration which yield an especial and individual character to volcanoes, although the cone of cinders and the craterare both wholly independent of the dimensions of the mountain. Vesuvius is more than three times lower than the Peakof Teneriffe ; its cone

ment desRoches, p. 321. Most of the volcanoes in Java demonstrate that thecause of the perfect absence of lava streams in volcanoes of incessantactivity is not alone to be sought for in their form, position, and height.Leop. von Buch, Descr. Phys. des Iles Canaries, p. 419 ; Reinwardt andHoffmann, in Poggend., Annalen., bd. xii., s. 607.

of cinders rises to one third of the heightof the whole mountain, while the cone of cinders of the Peakis only $\frac{1}{22}$ of its altitude.[9] In a much higher volcano thanthat of Teneriffe, the Rucu Pichincha, other relations occur which approach more nearly to that of Vesuvius. Among allthe volcanoes that I have seen in the two hemispheres, theconical form of Cotopaxi is the most beautifully regular. Asudden fusion of the snow at its cone of cinders announces theproximity of the eruption. Before the smoke is visible in therarefied strata of air surrounding the summit and the openingof the crater, the walls of the cone of cinders are sometimesin a state of glowing heat, when the whole mountain presentsan appearance of the most fear-

[9][It may be remarked in general, although the rule is liable to exceptions, that the dimensions of a crater are in an inverse ratio to theelevation of the mountain. Daubeney, op. cit., p. 444.] –Tr.

ful and portentous blackness.The crater, which, with very few exceptions, occupies thesummit of the volcano, forms a deep, caldronlike valley, whichis often accessible, and whose bottom is subject to constant alterations. The great or lesser depth of the crater is in manyvolcanoes likewise a sign of the near or distant occurrence ofan eruption. Long, narrow fissures, from which vapors issueforth, or small rounding hollows filled with molten masses, alternately open and close in the caldronlike valley ; the bottomrises and sinks, eminences of scori and cones of eruption areformed, rising sometimes far over the walls of the crater, andcontinuing for years together to impart to the volcano a peculiar character, and then suddenly fall together and disappearduring a new eruption. The openings of these cones of eruption, which rise from the bottom of the crater, must not, as istoo often done, be confounded with the crater which inclosesthem. If this be inaccessible from extreme depth and fromthe perpendicular descent, as in the case of the volcano ofRucu Pichincha, which is 15,920 feet in height, the travelermay look from the edge on the summit of the mountains whichrise in the sulphurous atmosphere of the valley at his feet ;and I have never beheld a grander or more remarkable picturethan that presented by this volcano. In the interval betweentwo eruptions, a crater may either present no luminous appearauce, showing merely open fissures and ascending vapors,or the scarcely heated soil may be covered by eminences ofscori, that admit of being approached without danger, andthus present to the geologist the spectacle of the eruption ofburning and fused masses, which fall back on the ledge of thecone of scoriz, and whose appearance is regularly announcedby small wholly local earthquakes. Lava sometimes streamsforth from the open fissures and small hollows, without breaking through or escaping beyond the sides of the crater. If,however, it does break through, the newlyopened terrestrialstream generally flows in such a quiet and welldefined course,that the deep valley, which we term the crater, remains accessible even during periods of eruption. It is impossible, without an exact representation of the configurationthe normaltype, as it were, of fireemitting mountains, to form a just ideaof those phenomena which, owing to fantastic descriptions andan undefined phraseology, have long been comprised under thehead of craters, cones of eruption, and volcanoes.

The marginal ledges of craters vary much less than one would be ledto suppose. A comparison of Saussures measurements withmy own yields the remarkable result, for instance, that in thecourse of fortynine years (from 1773 to 1822), the elevationof the northwestern margin of Mount Vesuvius (Rocca delPalo) may be considered to have remained unchanged.[10]

Volcanoes which, like the chain of the Andes, lift their summits high above the boundaries of the region of perpetual snow,present peculiar phenomena. The masses of snow, by theirsudden fusion during eruptions, occasion not only the most fearful inundations and torrents of water, in which smoking scorizare borne along on thick masses of ice, but they

[10]See the groundwork of my measurements compared with those ofSaussure and Lord Minto, in the Abhandlungen der Akademie der Wiss.zu Berlin for the years 1822 and 1823.

likewise exercise a constant action, while the volcano is in a state of perfect repose, by infiltration into the fissures of the trachytic rock.Cavities which are either on the declivity or at the foot of themountain are gradually converted into subterranean reservoirsof water, which communicate by numerous narrow openingswith mountain streams, as we see exemplified in the highlandsof Quito. The fishes of these rivulets multiply, especially inthe obscurity of the hollows; and when the shocks of earthquakes, which precede all eruptions in the Andes, have violently shaken the whole mass of the voleano, these subterranean caverns are suddenly opened, and water, fishes, and tufaceous mud are all ejected together. It is through this singularphenomenon[11] that the inhabitants of

[11]Pimelodes cyclopum. See Humboldt, Recueil dObservations

the highlands of Quitobecame acquainted with the existence of the little cyclopic-fishes, termed by them the prefiadilla. On the night betweenthe 19th and 20th of June, 1698, when the summit of Carguairazo, a mountain 19,720 feet in height, fell in, leavingonly two huge masses of rock remaining of the ledge of thecrater, a space of nearly thirtytwo square miles was overflowed and devastated by streams of liquid tufa and argillaceous mud (odazales), containing large quantities of dead fish.

In like manner, the putrid fever, which raged seven years previously in the mountain town of Ibarra, north of Quito, wasascribed to the ejection of fish from the voleano of Imbaburu.[12]

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deZoologie et d Anatomie Comparée, t. i., p. 2125.

[12] [It would appear, as there is no doubt that these fishes proceed fromthe mountain itself, that there must be large lakes in the interior,

Water and mud, which flow not from the crater itself, butfrom the hollows in the trachytic mass of the mountain, cannot, strictly speaking, be classed among volcanic phenomena.They are only indirectly connected with the volcanic activityof the mountain, resembling, in that respect, the singular me teorological process which I have designated in my earlier writings by the term of volcanic storm. The hot stream whichrises from the crater during the eruption, and spreads itself inthe atmosphere, condenses into a cloud, and surrounds the column of fire and cinders which rises to an altitude of manythousand feet. The sudden condensation of the vapors, and,as GayLussac has shown, the formation of a cloud of enormous extent, increase the electric tension. Forked

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whichin ordinary seasons are out of the immediate influence of the volcanioaction See Dauberey, op. cit., p. 488, 497.] – Tr.

lightningflashes from the column of cinders, and it is then easy to distinguish (as at the close of the eruption of Mount Vesuvius, inthe latter end of October, 1822) the rolling thunder of the volcanic storm from the detonations in the interior of the mountain. The flashes of lightning that darted from the volcaniccloud of steam, as we learn from Olafsens report, killed elevenhorses and two men, on the eruption of the volcano of Katlagia, in Iceland, on the 17th of October, 1755.

Having thus delineated the structure and dynamic activityof volcanoes, it now remains ter us to throw a glance at thedifferences existing in their material products. The subterranean forces sever old combinations of matter in order to produce new ones, and they also continue to act upon matter aslong as it is in a state of liquefaction from heat, and capableof being displaced. The greater or less pressure under whichmerely softened or wholly liquid fluids are solidified, appears toconstitute the main diflerence in the formation of Plutonic andvolcanic rocks. The mineral mass which flows in narrow,elongated streams from a volcanic opening (an earthspring),is called lava. Where many such currents meet and are arrested in their course, they expand in width, filling large basins, in which they become solidified in superimposed strata.These few sentences describe the general character of the products of volcanic activity.

Rocks which are nerely broken through by the voleanic action are often inclosed in the igneous products. Thus I havefound angular fragments of feldspathic syenite imbedded in theblack augitic lava of the voleano of Jorullo, in Mexico ; butthe masses of dolomite.and granular limestone, which containmagnificent clusters of crystalline fossils (vesuvian and garnets,covered with mejonite, nepheline, and sodalite), are not theejected products of Vesuvius, these belonging rather to verygenerally distributed formations, viz., strata of tufa, which aremore ancient than the elevation of the Somma and of Vesuvius, and are probably the products of a deepseated and coneealed submarine voleanic action.[13] We find five metals amongthe produets of existing voleanoes, iron, copper, lead, arsenic,and selenium, discovered by Stromeyer in the crater of Volcano.[14] The vapors that rise from the

[13]Leop. von Buch, in Poggend., Annales, bd. xxvii., p. 179.

[14][The little island of Volcano is separated from Lipari by a narrowchannel. It appears to have exhibited strong signs of volcanic activity long before vhe Christian era, and still emits gaseous exha-

fwmarolles cause the sublimation of the chlorids of iron, copper, lead, and ammonium ;iron glance[15] and chlorid of sodium (the latter often in largequantities) fill the cavities of recent lava streams and the fissures of the margin of the crater.

The mineral composition of lava differs according to the nature of the crystalline rock of which the voleano is formed, theheight of the point where the eruption occurs, whether at thefoot of the mountain or in the neighborhood of the crater, andthe condition of temperature of the interior. Vitreous voleanicformations, ob-

lations.Stromeyer detected the presence of selenium in a mixture of sal ammoniac aud sulphur. Another product, supposed to be peculiar to thisvolcano, is boracic acid, which lines the sides of the cavities in beautiful white silky crystals. Daubeney, op. cit., p. 257.] – Tr.

[15]Regarding the chemical origin of iron glance in volcanic masses, seeMitscherlich, in Poggend., Annalen, bd. xv., 8. 630; and on the liberation of hydrochloric acid in the crater, see GayLussac, in the Annalade Chimique et de Physique, t. xxii., p. 423.

sidian, pearlstone, and pumice, are entirely wanting in some volcanoes, while in the case of others they only proceed from the crater, or, at any rate, from very considerale heights. These important and involved relations ean onlybe explained by very accurate crystallographic and chemicalinvestigations. My fellow-traveler in Siberia, Gustav Rose,and subsequently Hermann Abich, have already been able,by their fortunate and ingenious researches, to throw muchlight on the structural relations of the various kinds of volcanic rocks.

The greater part of the ascending vapor is mere steam.When condensed, this forms springs, as in Pantellaria,[16] wherethey are used by the goatherds of the island. On

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[16] [Steam issues from many parts of this insular mountain, and several hut springs gush forth from it, which form together a lake 6000 feetin circumference. Daubeney, op. cit.] – Tr.

the morning of the 26th of October, 1822, a current was seen to flowfrom a lateral fissure of the crater of Vesuvius, and was longsupposed to have been boiling water; it was, however, shown,by Monticellis accurate investigations, to consist of dry ashes,which fell like sand, and of lava pulverized by friction. Theashes, which sometimes darken the air for hours and days together, and produce great injury to the vineyards and olivegroves by adhering to the leaves, indicate by their columnarascent, impelled by vapors, the termination of every greatearthquake. This is the magnificent phenomenon which-Pliny the younger, in his celebrated letter to Cornelius Tacitus,compares, in the case of Vesuvius, to the form of a lofty andthicklybranched and foliaceous pine. That which is described as flames inthe eruption of scoriw, and the radianceof the glowing red clouds that hover over the crater, can notbe ascribed to the effect of hydrogen gas in a state of combustion. They are rather reflections of light which issue frommolten masses, projected high in the air, an also reflectionsfrom the burning depths, whence the glowing vapors ascend.We will not, however, attempt to decide the nature of theflames, which are occasionally seen now, as in the time ofStrabo, to rise from the deep sea during the activity of littoral.volcanoes, or shortly before the elevation of a volcanic island.

When the questions are asked, what is it that burns in thevolcano what excites the heat, fuses together earths andmetals, and imparts to lava currents of thick layers a degreeof heat that lasts for many years?[17] it is necessarily impliedthat volcanoes must be connected with the existence of substances capable of maintaining combustion, like the beds ofcoal in subterranean fires. According to the different phasesof chemical science, bitumen, pyrites, the moist admixture offinelypulverized sulphur and iron, pyrophoric substances, andthe metals of the alkalies and earths, have in turn been designated as the cause of intensely active volcanic phenomena.The great chemist, Sir Humphrey Davy, to whom we are indcbted for the knowledge of the most combustible metallic substances, has himself renounced his bold cherzical hypothestsin his last work (Consolation in Travel, and last Days of aPhilosopher)a work which can not fail to

[17]See the beantiful experiments on the cooliag of masses of rock, inBischofs Warmelehre, s. 384, 443, 500512.

excite in thereader a feeling of the deepest melancholy. The great meandensity of the earth (544), when compared with the specificweight of potassium (0865), of sodium (0972), or of themetals of the earths (12), and the absence of hydrogen gas inthe gaseous emanations from the fissures of craters, and fromstill warm streams of lava, besides many chemical considerations, stand in opposition with the earlier conjectures of Davyand Ampére.[18] If hydrogen were evolved from erupted lava,how great must be the quantity of the gas disengaged, when,the seat of the volcanic activity being very low, as in the caseof the remarkable eruption at the foot of the Skaptar Jokul inIceland

[18]See Berzelius and Wohler, in Poggend., Annalen, bd. i., s. 221, andbd. xi., s. 146; GayLussac, in the Annales de Chimie, t. x., xii., p. 422;and Bischofs Reasons against the Chemical Theory of Volcanoes, in theEnglish edition of his Warmelehre, p. 297-309.

(from the 11th of June to the 3d of August, 1783,described by Mackenzie and Soemund Magnussen), a space ofmany square miles was covered by streams of lava, accumulated to the thickness of several hundred feet Similar difficulties are opposed to the assumption of the penetration of theatmospheric air into the crater, or, as it is figuratively expressed, the izhalation of the earth, when we have regard tothe small quantity of nitrogen emitted. So general, decpseated, and farpropagated an activity as that of volcanoes,can not assuredly have its source.in chemical affinity, or inthe mere contact of individual or merely locally distributedsubstances. Modern geognosy[19] rather seeks

[19][On the various theories that have been advanced in explanation ofvoleanic action, see Daubeney On Volcanoes, a work to which we havemade continual reference during the preceding pages, as it constitutesthe most recent and perfect compendium of all the impor-

the cause of thisactivity in the increased temperature with the increase ofdepth at all degrees of latitude, in that powerful internal heatwhich our planet owes to its first solidification, its formationin the regions of space, and to the spherical contraction of matter revolving elliptizally in a gaseous condition. We havethus mere conjecture and supposition side by side with certain knowledge. A philosophical study of nature strives everto elevate itself above the narrow requirements of mere naturaliescription, and does not consist, as

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tant facts relating to this subject, and is peculiarly adapted to serve as a source ofreference to the Cosmos, since the learned author in many instances enters into a full exposition of the views advanced by Baron Humboldt.The appendix contains several valuable notes with reference to themost recent works that have appeared on the Continent, on subjects relating to voleanoes; among others, an interesting notice of ProfessorBischofs views on the origin of the carbonic acid discharged fromvolcanoes, as enounced in his recently published work, Lehrbuch derChemischen und Physikalischen Geologie.] – Tr.

we have already remarked, in the mere accumulation of isolated facts. The inquiring and active spirit of man must be suffered to pass from thepresent to the past, to conjecture all that can not yet be knownwith certainty, and still to dwell with pleasure on the ancientmyths of geognosy which are presented to us under so manyvarious forms. Jf we consider volcanoes as irregular intermittent springs, emitting a fluid mixture of oxydized metals,alkalies, and earths, flowing gently and calmy wherever theyfind a passage, or being upheaved by the powerful expansiveforce of vapors, we are involuntarily led to remember the geognostic visions of Plato, according to which hot springs, as wellas all volcanic igneous streams, were eruptions that might betraced back to one generally distributed subterranean cause, Pyriphlegethon.[20]

[20]According to Platos geognostic views, as developed in the Phedo,Pyriphlegethon plays much the same part in relation to the activity ofvolcanoes that we now ascribé to the augmentation of heat as we descend from the earths surface, and to the fused condition of its internalstrata. (Phedo, ed. Ast, p. 603 and 607; Annot., p. 808 and 817.)Within the earth, and all around it, are larger and smaller caverns.Water flows there in abundance; also much fire and large streams offire, and streams of moist mud (some purer and others more filthy),like those in Sicily, consisting of mud and fire, preceding the great eruption, These streatns fill all places that fall in the way of their course.Pyriphlegethon flows forth into an extensive district burning with afierce fire, where it forms a lake larger than our sea, boiling with waterandmud. From thence it moves in circles round the earth, turbid andmuddy. This stream of molten earth and mud is so much the generalcause of volcanic phenomena, that Plato expressly adds, thus is Pyriphlegethon constituted, from which also the streams of fire (oi Adaxec),wherever they reach the earth (677 dv ruywor tij yijc), inflate suchparts (detached fragments). Volcanic scorie and lava streams aretherefore portions of Pyriphlegethon itself, portions of the subterraneanmolten and everundulating mass. That ol biaxec are lava streams, andnot, as Schneider, Passow, and Schleiermacher will have it, firevomiting mountains, is clear enough from many passages, some of whichhave been collected by Ukert (Geogr. der Griechen und Rémer, th. ii.,8. 200); pag is the velcanic phenomenon in reference to its most striking characteristic, the lava stream. Hence the expression, the piaxeof tna. Aristot., Mirab.

The different voleanoes over the earths surface, when theyare considered independently of all climatic differences, areecutely and characteristically classified as

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Ausc., t. ii., p. 833; sect. 38, Bekker;Thucyd., iii., 116; Theophrast., De Lap., 22, p. 427, Schneider; Diod.,v., 6, and xiv., 59, where are the remarkable words, Many placesnear the sea, in the neighborhood of tna, were leveled to the ground,trd tod Kadovuévov pbaxog; Strabo, vi. p. 269; xiii., p. 268, and where there is a notice of the celebrated burning mud of the Lelantineplains, in Eubeea, i., p. 58, Casaub.; and Appian, De Bello Civili, v.,114. The blame which Aristotle throws on the geognostical fantasiesof the Phedo (Meteor., ii., 2,19) is especially applied to the sources ofthe rivers flowing over the earths surface. The distinct statement ofPlato, that in Sicily eruptions of wet mud precede the glowing agstream, is very remarkable. Observations on Atna could not have leto such a statement, unless pumice and ashes, formed into a mudlikemass by admixture with melted snow and water, during the volcanoelectric storm in the crater of eruption, were mistaken for ejected mud.It is more probable that Platos streams of moist mud (vypod awyAodmoTauot) originated in a faint recollection of the salses (mud volcanaes)of Agrigentum, which, as I have already mentioned, eject argillaceousmud with a loud noise. It is much to be regretted, in reference to thissubject, that the work of Theophrastus zepe puaxoe tov ev EixeAca, Onthe Volcanic Stream in Sicily, to which Diog. Laert., v., 49, refers, hasnot come down to us.

central and linearvoleanoes. Under the first name are comprised those which-constitute the central point of many active mouths of eruption, distributed almost regularly in all directions ; under thesecond, those lying at some little distance from one another,forming, as it were, chimneys or vents along an extendedfissure. Linear volcanoes again admit of further subdivision,namely, those which rise like separate conical islands from thebottom of the sea, being generally parallel with a chain ofprimitive mountains, whose foot they appear to indicate, andthose voleanic chains which are elevated on the highest ridgesof these mountain chains, of which they form the summits.[21] The Peak of Teneriffe, for instance,

[21] Leopold von Buch, Physikal. Beschreib. der Canarischen Inseln, 8.326407. I doubt if we can agree with the ingenious Charles Darwin(Geological Observations on Volcanic Islands, 1844, p. aa in

is a central volcano, beingthe central point of the volcanic group to which the eruptic-nof Palma and Lancerote may be referred. The long, rampartlike chain of the Andes, which is sometimes single, and sometimes divided into two or three parallel branches, connectedby various transverse ridges, presents, from the south of Chilito the northwest coast of America, one of the grandest in.stances of a continental volcanic chain. The proximity of active volcanoes is always manifested in the chain of the Andes by the appearance of certain rocks (as dolerite, melaphyre,trachyte, andesite, and dioritic porphyry), which di-

regarding central volcanoes in general as volcanic chains of small extent onparallel fissures. Friedrich Hoffman believes that in the group of theLipari Islands, which he has so admirably described, and in which twoeruption fissures intersect near Panaria, he has found an intermediatetink between the two principal modes in which volcanoes appear,namely, the central volcanoes and volcanic chains of Von Buch (Poggendort, Annalen der Physik, bd. xxvi., 8. 8188).

vide the socalled primitive rocks, the transition slates and sandstones, andthe stratified formations. The constant recurrence of thisphenomenon convinced me long since that these sporadic rockswere the seat of voleanic phenomena, and were connected withvoleanic eruptions. At the foot of the grand Tunguragua,near Penipe, on the banks of the Rio Puela, I first distinctlyobserved mica slate resting on granite, broken through by avolcanic rock.

In the volcanic chain of the New Continent, the separatevolcanoes are occasionally, when near together, in mutual dependence upon one another ; and it is even seen that the volcanic activity for centuries together has moved on in one andthe same direction, as, for instance, from north to south in theprovince of Quito.[22] The focus

[22]Humboldt, Geognost. Beobach, uber die Vulkane des

of the volcanic action lies below the whole of the highlands of this province; the onlychannels of communication with the atmosphere are, however, those mountains which we designate by special names, aythe mountains of Pichincha, Cotopaxi, and Tunguragua, andwhich, from their grouping, elevation, and form, constitute thegrandest and most picturesque spectacle to be found in anyvolcanic district of an equally limited extent. Experienceshows us, in many instances, that the extremities of suchgroups of volcanic chains are connected together by subterranean communications ; and this fact reminds us of the ancientand true expression made use of by Seneca,[23] that the igneousmountain

Hochlandes vonQuito, in Poggend., Annal. der Physik, bd. xliv., s. 194.

[23]Seneca, while he speaks very clearly regarding the problematicalsinking of tna, says in his 79th letter, Though this might hap-

is only the issue of the more deeplyseated volcanicforces. In the Mexican highlands a mutual dependence is also observed to exist among the volcanic mountains Orizaba, Popocatepetl, Jorullo, and Colima; and I have shownthat they al lie in one direction between 18 59 and 19 12north latitude, and are situated in a transverse fissure runningfrom sea to sea. The volcano of Jorullo broke forth on the29th of

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pen,not because the mountains height is lowered, but because the fires areweakened, and do not blaze out with their former vehemence ; and forwhich reason it is that such vast clouds of smoke are not seen in thedaytime. Yet neither of these seem incredible, for the mountain maypossibly be consumed by being daily devoured, and the fire not be solarge as formerly, since it is not selfgenerated here, but is kindled inthe distant bowels of the earth, and there rages, being fed with continual fuel, not with that of the mountain, through which it only makesits passage. The subterraiean communication, by galleries, between the volcanoes of Sicily, Lipari, Pithecusa (Ischia), and Vesuvius,of the last of which we may conjecture that it formerly burned and presented a fiery circle, seems fully understood by Strabo (lib. i., p247 and 248). He terms the whole distric subigneous.

September, 1759, exactly in this direction, and overthe same transverse fissure, being elevated to a height of 1604feet above the level of the surrounding plain. The mountaironly once emitted an eruption of lava, in the same manner asis recorded of Mount Epomeo in Ischia, in the year 1302But although Jorullo, which is eighty miles from any activevolcano, is in the strict sense of the word a new mountain, itmust not be compared with Monte Nuovo, near Puzzuolo,which first appeared on the 19th of September, 1538, and israther to be classed among craters of elevation. I believethat I have furnished a more natural explanation of the eruption of the Mexican volcano, in cdmparing its appearance tothe elevation of the Hill of Methone, now Methana, in thepeninsula of Trezene. The description given by Strabo andPausanias of this elevation, led one of the Roman poets, mostcelebrated for his richness of fancy, to develop views whichagree in a remarkable manner with the theory of moderngeognosy. Near Trezene is a tumulus, steep and devoid oftrees, once a plain, now a mountain. The vapors inclosed indark caverns in vain seek a passage by which they may escape.The heaving earth, inflated by the force of the compressedvapors, expands like a bladder filled with air, or like a goatskin. The ground has remained thus inflated, and the highprojecting eminence has been solidified by time into a naked.rock. Thus picturesquely, and, as analogous phenomenajustify us in believing, thus truly has Ovid described thatgreat natural phenomenon which occurred 282 years beforeour era, and, consequently, 45 years before the volcanic separation of Thera (Santorino) and Therasia, between Trezeneand Epidaurus, on the same spot where Russegger has foundveins of trachyte.[24]

[24]Humboldt, Essai Politique sur la Nouv. Espagne, t. ii., p. 173175t Ovids description of the eruption of Methone (Metam., xv., p. 296-306):

> Near Troszene stands a hill, exposed in air To winter winds, of leafy shadows bare This once was level ground; but (strange to tell) The included vapors, that in caverns dwell, Laboring with colic pangs, and close confined, In vain sought issue for the rumbling wind Yet still they heaved for vent, and heaving still Enlarged the concave and shot up the hill As breath extends a bladder, or the skins Of goats are blown t inclose the hoarded wines ; The mountain yet retains a mountains face, And gathered rubbish heads the hollow space.

– Dryden's Translation.

This description of a domeshaped elevation on the continent is ofgreat importance in a geognostical point of view, and coincides to a remarkable degree with Aristotles account (Meteor., ii., 8, 1719) of theupheaval of islands of eruption The heaving of the earth does notcease till the wind (dvezoc) which occasions the shocks has made itsescape into the crustof the earth. It is not long ago since

Santorino is the most important of all he islands of eruptzon belonging to volcanic chains.[25] It combines within itself the his-

this. actuallyhappened at Heraclea in Pontus, and a similar event formerly occurredat Hiera, one of the Holian Islands. A portion of the earth swelled up,and with loud noise rose into the form of a hill, till the mighty urgingblast (avedua) found an outlet, and ejected sparks and ashes whichcovered the neighborhood of Lipari, and even extended to severalItalian cities. In this description, the vesicular distension of theearths crust (a stage at which many trachytic mountains have remained)is very well distinguished from the eruption itself. Strabo, lib. i., p.59 (Casaubon), likewise describes the phenomenon as it occurred atMethone near the town, in the Bay of Hermione, there arose a flamingeruption; a fiery mountain, seven () stadia in height, was then thrownup, which during the day was inaccessible from its heat and sulphureous stench, but at night evolved an agreeable odor (7), and was so hotthat the sea boiled for a distance of five stadia, and was turbid for fulltwenty stadia, and also was filled with detached masses of rock. Regarding the present mineralogical character of the peninsula of Methana,see Fiedler, Reise durch Griechenland, th. i., 8. 257-263.

[25][I am indebted to the kindness of Professor E. Forbes for the following interesting account of the island of Santorino, and the adjacentislands of Neokaimeni and Microkaimeni. The aspect of the bay isthat of a great crater filled with water, Thera and Therasia forming iiswalls, and the other islands being afterproductions in its center. Wesounded with 250 fathoms of line in the middle of the bay, be-

tory of all islands of elevation. For upward of2000 years, as far as history and tradition certify, it wouldappear as if nature were striving to form a volcano in themidst of the crater of elevation.[26] Similar insu-

tweenTherasia and the main islands, but got no bottom. Both these islandsappear to be similarly formed of successive strata of volcanic ashes,which, being of the most vivid and variegated colors, present a strikingcontrast to the black and cindery aspect of the central isles. Neokaimeni, the lastformed island, is a great heap of obsidian and scorie.So, also, is the greater mass, Microkaimeni, which rises up in a conicalform, and has a cavity or crater. On one side of this island, however,a section is exposed, and cliffs of fine pumiceous ash appear stratifiedin the greater islands. In the main island, the volcanic strata abutagainst the limestone mass of Mount St. Elias in such a way as to leadto the inference that they were deposited in a sea bottom in which thepresent mountain rose as a submarine mass of rock. The people atSantorino assured us that subterranean noises are not unfrequentlyheard, ore during calms and south winds, when they say thewater of parts of the bay becomes the color of sulphur. My own impression is, that this group of islands constitutes a crater of elevation,of which the outer ones are the remains of the walls, while the centralgronp are of later origin, and consist partly of upheaved sea bottoms and partly of erupted mattererupted, however, beneath the surfaceof the water.] – Tr.

[26] Leop. von Buch, Physik. Beschr. der Canar. Insein, 8.

lar elevations, and almost always at regular intervals of 80 or 90years,[27] have been manifested in the island of St. Michael, inthe Azores; but in this case the bottom of the sea has notbeen elevated at exactly the same parts.[28] The island whichCap-

356358,and particularly the French translation of this excellent work, p. 402 ;and his memoir in Poggendorfs Annalen, bd. xxxviii., 8. 183. A submarine island has quite recently made its appearance within the craterof Santorino. In 1810 it was still fifteen fathoms below the surface ofthe sea, but in 1830 it had risen to within three or four. It rises steeply,like a great cone, from the bottom of the sea, and the continuous activity of the submarine crater is obvious from the circumstance that sulphurous acid vapors are mixed with the sea water, in the eastern bayof Neokaimeni, in the same manner as at Vromolimni, near Methana.Coppered ships lie at anchor in the bay in order to get their bottomecleaned and polished by this natural (volcanic) process. (Virlet, in theBulletin de la Société Géologique de France, t. iii., p. 109, and Fiedler,Reise durch Griechenland, th. ii., 8. 469 and 584.)

[27] Appearance of a new island near St. Miguel, one of the Azores, 11thof June, 1638, 31st of December, 1719, 13th of June, 1811.

[28] [My esteemed friend, Dr. Webster, professor of Chemistry and-Mineralogy at Harvard College, Cambridge, Massachusetts, U. S., inhis Description of the Island of St. Michael, c., Boston, 1822, gives aninteresting account of the sudden appearance of the island named

tain Tillard named Sabrina, appeared unfortunately ata time (the 30th of January, 1811) when the political relations of the maritime nations of Western Europe preventedthat attention being bestowed upon the subject by scientificinstitutions which was afterward directed to the sudden appearance (the 2d of July, 1831), and the speedy destruction ofthe igneous island of Ferdinandea in the Sicilian Sea, between the limestone shores of Sciacca and the purely volcanic islandof Pantellaria.[29]

Sabrina, which was about a mile in circumference, and two or three hundred feet above the level of the ocean. After continuing for some weeks, it sank into the sea. Dr. Webster describes the whole of theisland of St. Michael as volcanic, and containing a number of conicalhills of trachyte, several of which have craters, and appear at someformer time to have been the openings of volcanoes. The hot springswhich abound in the island are impregnated with sulphureted hydrogen and carbonic acid gases, appearing to attest the existence of volcanic action.] – Tr.

[29]Prévost,in the Bulietin de la Société Géologique, t. iii., p.34; Friedsvich Hoffman, Hinterlassene Werke. bd. ii., s. 451456.

The geographical distribution of the volcanoes which havebeen in a state of activity during historical times, the great-number of insular and littoral voleanic mountains, and the occasional, although ephemeral, eruptions in the bottom of the-sea, early led to the belief that volcanic activity was connected with the neighborhood of the sea, and was dependent uponit for its continuance. For many hundred years, says Justinian, or rather Trogus Pompeius, whom he follows,[30] AZtnaand

[30]Accedunt vicini et perpetui tne montis ignes et insularum-Zolidum, veluti ipsis undis alatur incendium; neque enim aliter duraretot seculis tantus ignis potuisset, nisi humoris nutrimentis aleretur.(Justin, Hist. Philipp., iv., i.) The volcanic theory with which. thephysical description of Sicily here begins is extremely intricate. Deepstrata of sulphur and resin; a very thin soil full of cavities and easilyfissured ; violent motion of the waves of the sea, which, as they striketogether, draw down the air (the wind) for the maintenance of the firesuch are the elements of the theory of Trogus. Since he seems fromPliny (xi., 52) to have been a physiognomist, we may presume that nisnumerous lost works were not confined to history

alone. The opinionthat air is forced into the interior of the earth, there to act on the volcanic furnaces, was connected by the ancients with the supposed inruence of winds from different quarters on the intensity of the fires burning in tna, Hiera, and Stromboli. (See the remarkable passage inStrabo, lib. vi., p. 275 and 276.) The mountain island of Stromboli(Strongyle) was regarded, therefore, as the dwellingplace of Holus,the regulator of the winds, in consequence of the sailors foretellingthe weather from the activity of the volcanic eruptions of this island.The connection between the eruption of a small volcano with the stateof the barometer and the direction of the wind is still generally recognized (Leop. von Buch, Deser. Phys. des Iles Canaries, p. 334; Holtmann, in Poggend., Annalen, bd. xxvi., 8. vii), although our presentknowledge of volcanic puenomena, and the slight changes of atinospheric pressure accompanying our winds, do not enable us to offer anysatisfactory explanation of the fact. Bembo, who during his youth wasbrought up in Sicily by Greek refugees, gave an agreeable narrative ofhis wanderings, and in his Hina Dialogus (written in the middle ofthe sixteenth century) advances the theory of the penetration of seawater to the very center of the volcanic action, and of the necessity ofthe proximity of the sea to active volcanoes. In ascending Etna thefollowing question was proposed Explana potius nobis que petimus,ea incendia unde oriantur et orta quomodo perdurent. In omni tellurenuspiam majores fistula aut meatus ampliores sunt quam in locis, quevel mari vicina sunt, vela mariprotinus alluuntur mare erodit llafacillime pergitque in viscera terre. Itaque cum in aliena regua sibiviam faciat, ventis etiam facit; ex quo fit, ut loca queque maritimamaxime terre motibus subjecta sint, parum mediterranea. Habesgaum in sulfuthe Aolian Islands have been burning, and how couldthis have continued so long if the fire had not been fed by the neighboring sea?[31] Jn order to exp.ain the necessity of thevicinity of the sea, recourse has been had, even in moderntimes, to the hypothesis .of the penetration of sea water intothe foci of volcanic agency, that is to say, into

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ris venas venti furentes inciderint, unde incendia orianturAine tue. Vides, que mare in radicibus habeat, que sulfurea sit,qute cavernosa, que a mari aliquando perforata ventos admiserit estugntes, per quos idonea flamme materies incenderetur.

[31] [Although extinct volcanoes seem by no means confined to theneighborhood of the present seas, being often scattered over the mostinland portions of our existing continents, yet it will appear that, at thetime at which they were in an active state, the greater part were in theneighborhood either of the sea, or of the extensive salt or fresh waterlakes, which existed at that period over much of what is now dry land.This may be seen either by referring to Dr. Boués map of Europe, orto that published by Mr. Lyell in the recent edition of his Principles ofGeology (1847), from both of which it will become apparent that, at acomparatively recent epoch, those parts of France, of Germany, ofHungary, and of Italy, which afford evidences of volcanic action nowextinct, were covered by the ocean. Daubeney On Volcanoes, p. 605.] – Tr.

deepseatedterrestrial strata. When I collect together all the facts thatmay be derived from my own observation and the laboriousresearches of others, it appears to me that every thing in thisinvolved investigation depends upon the questions whether thegreat quantity of aqueous vapors, which are unquestionablyexhaled from volcanoes even when in a state of rest, be derived from sea water impregnated with salt, or rather, perhaps,with fresh meteoric water; or whether the expansive force ofthe vapors (which, at a depth of nearly 94,000 feet, is equalto 2800 atmospheres) would be able at different depths tocounterbalance the hydrostatic pressure of the sea, and thusafford them, under certain conditions, a free access to thefocus ;[32] or whether the formation of

[32]Compare GayLussac, Sur les Volcans, in the Annales de

metallic chlorids, thepresence of chlorid of sodium in the fissures of the crater, andthe frequent mixture of hydrochloric acid with the aqueousvapors, necessarily imply access of sea water; or, finally,whether the repose of voleanoes (either when temporary, orpermanent ard complete) depends upon the closure of thechannels by which the sea or meteoric water was conveyed,or whether the absence of flames and of exhalations of hydrogen(and sulphureted hydrogen gas seems more characteristic ofsolfataras than of active volcanoes) is not directly at variance with the hypothesis of the decomposition of great masses ofwa-

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Chimie,t. xxii, p. 427, and Bischof, Warmelehre, s. 272. The eruptions ofsmoke and steam which have at different periods been seen in Lancerote, Iceland, and the Kurile Islands, during the eruption of the neighboring volcanoes, afford indications of the reaction of volcanic focithrough tense columns of water; that is to say, these phenomena occur when the expansive force of the vapor exceeds the hydrostaticpressure.

ter?[33]

The discussion of these important physical questions doesnot come within the scope of a work of this nature ; but, whilewe are considering these phenomena, we would enter somewhatmore into the question of the geographical distribution of stillactive volcanoes. We find, for instance, that in the New World,three, viz., Jorullo, Popocatepetl, and the voleano of De laFragua, are situated at the respective distances of 80, 132,and 196 miles from the seacoast, while in Central Asia, asAbel Rémusatt[34] first made known to geognosists, the Thianschan (Celestial Mountains), in which are situated the lavaemitting mountain of Peschan, the solfatara of

[33] [See Daubeney On Volcanoes, Part iii., ch. xxxvi., xxxviii., xxxix.] – Tr.

[34] Abel Rémusat, Lettre a M. Cordier, in the Annales de Chimie, t. v.,p. 137.

Urumtsi, andthe still active igneous mountain (Hotschen) of Turfan, lie atan almost equal distance (1480 to 1528 miles) from the shoresof the Polar Sea and those of the Indian Ocean. Peschan isalso fully 1360 miles distant from the Caspian Sea,[35] and 172and 218 miles from the seas of Issikul and Balkasch. It isa fact worthy of notice, that among the four great parallel-mountain chains which traverse the Asiatic continent fromeast to west, the Altai, the Thianschan, theKuenlun, andthe Himalaya, it is not the latter chain, which is nearest tothe ocean, but the two inner ranges, the Thianschan and theKuenlun, at the distance of 1600 and 720 miles from the sea,which have fireemitting mountains

[35]Humboldt, Asie Centrale, t. ii., p. 3033, 3852, 7080, and 426428.The existence of active volcanoes in Kordofan, 540 miles from the RedSea, lias been recently contradicted by Ruppell, Reisen in Nubien, 1829,6. 151.

like (tna and Vesuvius,and generate ammonia like the volcano of Guatimala. Chinese writers undoubtedly speak of lava streams when they describe the emissions of smoke and flame, which, issuing fromPeschan, devastated a space measuring ten li[36] in the firstand seventh centuries of our era. Burning masses of stoneflowed, according to their description, like thin melted fat.The facts that have been enumerated, and to which sufficientattention has not been bestowed, render it probable that thevicinity of the sea, and the penetration of sea water to the fociof volcanoes, are not absolutely necessary to the eruption of subtcrranean fire, and that littoral situations only favor theeruption by forming the margin of a deep sea basin,

[36][A li is a Chinese measurement, equal to about one thirtieth of amile.] – Tr.

which,covered by strata of water, and lying many thousand feet lowerthan the interior continent, can offer but an inconsidetabledegree of resistance.

The present active voleanoes, which communicate by permanent craters simultaneously with the interior of the earthand with the atmosphere, must have been formed at a subsequent period, when the upper chalk strata and all the tertiaryformations were already present this is shown to be the factby the trachytic and basaltic eruptions which frequently formthe walls of the crater of elevation. Melaphyres extend to themiddle tertiary formations, but are found already in the Juralimestone, where they break through the variegated sandstone.[37] We must not

[37]Dufrénoy et Elie de Beaumont, Explication de la Carte Géologiquede la France, t. i., p. 89.

confound the earlier outpourings of granite, quartzose porphyry, and euphotide from temporary fissures in the oldtransition rocks with the present active volcanic craters.

The extinction of volcanic activity is either only partialin which case the subterranean fire seeks another passage ofescape in the same mountain chainor it is total, as in Auvergne. More recent examples are recorded in historical times,of the total extinction of the volcano of Mosychlos,[38] on theisland sacred to Hephzs-

[38]Sophocl., Philoct., v. 971 and 972. On the supposed epoch of theextinction of the Lemnian fire in the time of Alexander, compare Buttmann, in the Museum der Alterthumswissenschaft, bd. i., 1807, 8. 295;Dureau de la Malle, in MalteBrun, Annales des Voyages, t. ix., 1809,p 5; Ukert, in Bertuch, Geogr. Ephemeriden, bd. xxxix., 1812, s. 361;Rhode, Res Lemnice, 1829, p. 8; and Walter, Veber Abnahme der Vulkan. Thatigkeit in Historischen Zeiten, 1844,8 24. The chart of Lemnos, constructed by Choiseul, makes it extremely probable that the extinct crater of Mosychlos, and the island of Chryse, the desert habitationof Philoctetes (Otfried Miller, Minyer, s. 300),

tos (Vulcan), whose high whirlingflames were known to Sophocles ; and of the voleano of Medina, which, according to Burckhardt, still continued to pourout a stream of lava on the 2d of November, 1276. Everystage of volcanic activity, from its first origin to its extinction,is characterized by peculiar products; first by ignited scorie,streams of lava consisting of trachyte, pyroxene, and obsidian,and by rapilli and tufaceous ashes, accompanied by the development of large quantities of pure aqueous vapor ; subsequently, when the voleanc becomes a solfatara, by aqueous vaporsmixed with sulphureted hydrogen and carbonic acid gases ;and, finally, when it is completely cooled, by ex-

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have been long swallowed up by the sea. Reefs and shoals, to the northeast of Lemnos,still indicate the spot where the gean Sea once possessed an activeoe like Attna, Vesuvius, Stromboli, and Volcano (in the LipariIsles).

halations ofcarbonicacid alone. There is a remarkable class of igneousmountains which do not eject lava, but merely devastatingstreams of hot water, impregnated with burning sulphur androcks reduced to a state of dust (as, for instance, the Galungung in Java) ; but whether these mountains present a normalcondition, or only a certain transitory modification of the volcanic process, must remain undecided until they are visited bygeologists possessed of a knowledge of chemistry in its presentcondition.