THE SUMMIT OF MOUNT HAMILTON IN THE WINTER.

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—— 1035 ——

MOUNTAIN OBSERVATORIES

IN

AMERICA AND EUROPE.

BY

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CITY OF WASHINGTON:

PUBLISHED BY THE SMITHSONIAN INSTITUTION.

1896.

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MOUNTAIN OBSERVATORIES IN AMERICA AND EUROPE.

By Edward S. Holden.

INTRODUCTION.

The main object of the present paper is to study the conditions suitable for *astronomical* work at high levels. It has been necessary to examine the records of meteorological mountain-stations to obtain some of the required data: and the physiological questions involved could not be passed over, since, after all, the observer must be at the full height of his powers if he is to advance Science. But meteorological and physiological questions are here quite subordinate to the main purpose of the paper, which relates chiefly to purely astronomical matters.

It is interesting to note the expansion of the ideas connected with telescopic observation. Galileo and Kepler, (1609), considered the telescope alone. It was an optical instrument. When it was perfect, nothing more needed consideration. Newton (1717), whom nothing escaped, saw that vision might be better in the pure air of high mountains.

> If the theory of making telescopes could at length be fully brought into practice, yet there would be certain bounds beyond which telescopes could not perform. For the air through which we look upon the stars is in a perpetual tremor, as may be seen by the tremulous motion of shadows cast from high towers, and by the twinkling of the fixed stars. The only remedy is a most serene and quiet air, such as may perhaps be found on the tops of the highest mountains above the grosser clouds. *

Sir William Herschel was the first to consider the observer as a part of the apparatus. In 1782 he points out that to obtain the best results the observer, the air, and the instrument must be of one temperature. In 1794 he says, while re-observing the belts on *Saturn* and noting changes that had occurred: "I took care to bend my head so as to receive the picture of the belts in the same direction as [formerly]—as there was a possibility that the vertical diameter of the retina might be more or less sensitive than the horizontal one."

**Optics*, second edition, 1719, p. 107.

The investigations of Gauss and others for the telescope, and of Helmholtz and others in the optics of the eye, have taught us the imperfections of both these optical instruments. Newton's suggestion of 1717 has been carried out, in one form or another, by Bond (1851), Lassell (1852), Piazzi-Smyth (1856), and others, and has resulted in the foundation of mountain observatories like those of Mount Hamilton, Etna, Nice, etc. Galileo's tower at Arcetri is the forerunner of the magnificent establishments of modern times. The greatest telescopes of the world are but consequences of his "optick tube."

In the paragraphs which immediately follow I have brought together short accounts of the principal steps in the evolution of the idea of the modern observatory and its requirements. The succeeding chapters will treat the more important of these in still greater detail.

François de Plantade, an astronomer and geodesist of Montpellier (*b.* 1670, *d.* 1741), a colleague of Cassini, first proposed an astronomical observatory on the Pic-du-Midi, (9439 feet), and made several ascents with that end in view. He died, in fact, on the mountain while engaged in observations. The noted Chevalier D'Angos, it is said, made a series of astronomical observations at this station. In 1860 (July 18) a solar eclipse was photographed from the summit. It is worthy of note that the altitude of the station is the same as that of Quito, Ecuador.

In 1821–2–3 Sir John Herschel and Sir James South re-observed a number of Sir William Herschel's double-stars at Sir James South's London observatory. Finding that the conditions existing there were not satisfactory, Sir James South, in 1824, transported his largest telescope (aperture 5 inches) to Passy, in France, where the work was continued. This was, I believe, the first astronomical expedition in search of improved conditions. It was, however, entirely unnecessary to move a 5-inch telescope out of England in search of a climate. The southern counties, Sussex, etc., would have provided good observing stations.

In various works, Alexander Von Humboldt called attention to the steadiness of the stars in the tropics, where the distribution of temperature is more regular than in our temperate regions. On the rainless deserts of Peru the stars generally cease to twinkle at an altitude of 10° to 12°. In Arabia, India, and on the shores of the Persian Gulf similar conditions are said to prevail.

In the year 1851 a total solar eclipse occurred in Norway. The corona was observed by Professor G. P. Bond, Director of Harvard College Observatory, among others. Before leaving Norway, Bond determined to search for the corona by occulting the sun in full daylight, selecting some high station with an atmosphere free from dust and therefore from "glare" about the sun. From Norway Bond proceeded directly to Switzerland, where the experiment was tried.*

The 2-foot reflector constructed by Lassell and mounted by him near Liverpool was taken to Malta in 1852 chiefly for the purpose of obtaining better views of the planets. The 4-foot reflector, also constructed by Lassell in 1859, was mounted at Malta during 1861 and remained there until 1865. The change from England to Malta was made in search of better astronomical conditions; and it is noteworthy that Lassell's first expedition (1852) antedated the Teneriffe experiment by four years. Sir John Herschel's expedition to the Cape of Good Hope was not in search of better conditions but for the purpose of making a survey of the southern sky.

In the year 1856 Professor Piazzi-Smyth made his famous expedition to Teneriffe, where he established telescopes of sufficient power at two stations of altitudes of 8903 and 10,702 feet, respectively. The whole question of good vision † was thoroughly studied during a two months' stay. The effects of fogs, local clouds, wind, dust, moisture, etc. were noted. The general conclusion was extremely in favor of that particular mountain-station.

The results of the expedition were printed in scientific journals and also in a popular book which had a wide circulation.‡ There is no doubt that this expedition served to attract general attention to the matter of choosing suitable sites for observatories; and also to spread the idea that *all* mountain-stations possessed striking advantages.

Lassell's expedition of 1852 was, however, the first practical recognition of the fact that a large telescope can only do its work well under conditions specially favorable. These conditions *may* be found on a mountain, or (for some work) they *may* be found at sea-level, as at Malta. If the necessity for a specially favorable site be once recognized, the search for the proper conditions is a matter of detail. The credit for a clear comprehension of the conditions necessary for a great telescope we must give to Lassell.

Captain Jacob, a keen-sighted observer, early recognized the advantages of a good observing station. At the time of his death (1862) he had procured a 9-inch refractor which he intended to mount in the Nilgiri Hills (Southern India).

A letter from Dr. Henry Draper to Professor George P. Bond (dated November 21, 1864) suggests that the best place to establish a

* The *American Journal of Science*, 3d series, vol. x, pp. 81–83, contains accounts of this experiment extracted by the writer from Professor Bond's Ms. diary, by permission of his daughters.

† Good "seeing," as it is called in the United States—following a convenient expression which we owe, I think, to the veteran observer, Alvan Clark.

‡ *Teneriffe—An Astronomer's Experiment.*

large telescope for use in celestial photography might be on the west coast of South America, near the equator (for instance, in the neighborhood of Quito), and at a considerable altitude above the sea. A generation later this suggestion was realized in the Harvard Station at Arequipa.*

The first recognition by a scientific body of the matter in question was by the American Association for the Advancement of Science at its Chicago meeting (1868). Its action in 1868 was followed up by the appointment of a committee to memorialize Congress, in 1870. It is worth while to quote its resolutions in full, as they led to important results.

Resolved, That this Association recommends to the attention of those who would make intelligent and munificent endowments of scientific institutions, the importance of an Astronomical Observatory at some point on the Pacific Railroad between Nebraska and the Pacific Coast, and at as high an altitude as possible, where the clearness of the atmosphere and the great number of cloudless days would ensure remarkable and unsurpassed opportunities for astronomical observations.† [Adopted at the Chicago meeting, August, 1868.]

Resolved, That a committee of three be appointed to memorialize Congress on the importance of establishing an observatory and maintaining a scientific corps, for a year or more, at one of the highest points on the Pacific Railroad, and particularly at the eastern rim of the Utah Basin. [Adopted at the Troy meeting, August, 1870.]

The committee appointed consisted of J. E. Hilgard, Joseph Henry, and J. H. C. Coffin, and Congress was asked for an appropriation. A sum was granted, and the disbursement was put under the charge of the U. S. Coast Survey.

The subject must have been widely discussed among scientific men in America, for on several occasions before 1866 my honored friend and instructor, Professor William Chauvenet, explained to me the advantages to be gained from mountain-stations for astronomical observatories.

In the year 1872 the expeditions of the U. S. Coast Survey, under Professors Young and Davidson, and Mr. Cutts, were stationed in the Sierras and at Sherman (Wyoming); and the great success of Professor Young's solar spectroscopic researches at the latter station was soon widely known. In 1872–3 the question of a suitable site for the 26-inch telescope of the Naval Observatory was frequently discussed among astronomers. In 1873 I made a stay in Colorado and reported (adversely) on the placing of a great telescope in any of the stations

* I owe the knowledge of this unpublished letter to my cousin, Miss Elizabeth Bond, who has placed copies of her father's correspondence in my hands.

† It is noteworthy that nothing is said about the necessity for a steady atmosphere—the most important factor.

which I had occupied. In 1874 Mr. Lick proposed to found a mountain observatory, and the first plans for the Lick Observatory were made. An essential part of the programme was that the site should be selected only after telescopic comparisons had been instituted between the various stations proposed. Such an examination was actually made by Professor Burnham in 1879, after the present site for the Lick Observatory had been selected, but before any work had been done.

The eclipse-expeditions of 1878 to the Rocky Mountain region, familiarized many observers with the question; and the expedition of Dr. Langley to Mt. Whitney in 1881 exhibited the excellent conditions to be obtained there. The first regular astronomical observations were made at Mt. Hamilton (double stars; the transit of *Mercury*) in 1881, and the transit of *Venus* was observed (photographed) with excellent results in 1882. All these observations were published and did their part in calling attention to the problem. The observatory on Etna, built in 1881, but proposed by Professor Tacchini as early as 1871, performed the same part in Europe. It may fairly be said that the many mountain observatories now built, or building in all parts of the globe owe much to the experience gained at the establishments on Etna and at Mt. Hamilton.

These establishments themselves are the legitimate outcome of the proposal of Sir Isaac Newton in 1717, of the Malta expedition of Lassell in 1852, and of the Teneriffe experiment of Piazzi-Smyth in 1856.

The inhabitants of the earth know the external universe directly, only through the sense of sight; and our terrestrial views of the planets and stars are much modified by the action of our own atmosphere upon the rays of their light which reach our eyes. We are, as it were, immersed in an ocean of air, and one of the first problems of astronomical physics is to determine the effect of this overlying ocean upon the light from external bodies which penetrates its depths. Light moves in straight lines in empty space; but light entering our atmosphere is refracted from its course so that the ray which enters our eye from a star no longer travels in its primitive direction.

By the effect of refraction every star is seen not in its true place but displaced. Moreover the atmosphere does not permit all the light of the star to reach us. A certain quantity—percentage—is absorbed in its passage through the atmospheric envelope, and the star appears fainter to us in fact, than it would were the atmosphere removed. It appears less bright near the horizon than near the zenith. Not only is the *quantity* of incident light changed by the general absorption, but its *quality* is affected also by a selective absorption special to our air. Bodies appear redder than they really are. The blue light is more absorbed, proportionally, than the red. A familiar example of this is shown in the redness of the setting sun. If we measure the heat which comes to us from the sun we shall find that it is refracted, altered in quantity and also in quality by our own atmosphere.

One of the chief problems of astrophysics is to evaluate the amount of these alterations, so as to obtain the true and not merely the apparent effect of celestial radiations.

In order to measure the effect of the earth's atmosphere in these regards there are two obvious experimental methods. The observer may, first, remain in the same place, and make his measurements when the heavenly body is near the zenith (when its rays traverse the least depth of air) and again, when it is near the horizon (when its rays traverse the maximum depth). By a comparison of such observations the effect of the atmosphere can be concluded. Or, again, the observer may occupy two stations, one near the sea-level (and thus under the whole of the atmosphere), the other on a high mountain (and thus free from the effect of the air beneath). A comparison of such measures will, again, determine the influence of the earth's envelope. In many of the delicate problems of astronomy and physics, recourse must be had to both these devices. High-level observing stations are called for in many special researches.

Stars seen from the summit of a high mountain of about 10,000 feet in altitude appear considerably brighter than from sea-level, and the effect to an observer seems to be a brightening of the whole heavens.

This brightening is, however, not uniform over the entire sky. Stars at and near the zenith are but slightly more brilliant, while those near the horizon are about two and a half times brighter than at sea-level. The very vivid impression made upon an observer who first sees a clear night-sky from a high peak is chiefly due to the marked increase in the brilliancy of the stars, and of the Milky Way, close down to the horizon.*

If while the stars are more brilliant, because the air is more transparent, they are at the same time more steady (twinkle less), because the air is more tranquil, the advantages of a mountain station for astronomical purposes become very great. If these advantages are noteworthy for observations made with the eye and telescope, they are still more so when the eye is replaced by the photographic plate. The blue rays pass through the higher air relatively more freely than through the lower and denser.

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* At an elevation of 14,000 feet in the Sierras and Rocky Mountains the sky, on a cloudless and smokeless day, is *violet*, not blue. The skies of the paintings of Bierstadt, Moran, and others seem false to those who have never lived at these high altitudes, but they are not so.

At the Lick Observatory *both* the advantages named above are secured; that is, increased transparency and greatly increased steadiness. The astronomical observations made on the Säntis show the same to be sometimes true at this station, though both advantages are rarely secured at high mountain-stations.

In astronomical observations it is desirable that the image of the star under examination should be as bright as possible; and as steady as possible—as free from twinkling, as has been said. Of the two requirements the second is far more important for all observations in which accurate measures of the positions of stars are needed; and in most spectroscopic observations.

A striking demonstration of the relative importance of the two factors is often afforded during the times when a fog is slowly forming in the atmosphere. While the air is perfectly clear, both components of a double star, for example, seen through the telescope, will appear quite brilliant, but each component will be so unsteady (will twinkle so) that measures of their distance apart will be difficult to make. As the fog comes on, its effect is to equalize the temperatures of different layers of the atmosphere and thus to increase the *steadiness* of the star. At the same time another effect of the fog is to absorb some of the star's light and thus to decrease its brilliancy.

If the fog forms slowly, it is instructive to watch the gradual changes in brilliancy and to note how little effect these changes have upon the measures; and to remark, on the other hand, the great increase of precision in the measurements due to the increased steadiness of the star-images.

A transparent air is very desirable; a steady air is essential for most astronomical work.

The conditions which produce steady seeing depend, in general, upon the arrangement of the layers of atmosphere above the observing station. If we imagine the observer to be situated on an extensive level plain, as on the steppes of Russia, a small island in the tropical ocean, or the plains of Lombardy, and if the air is quite still, the separate layers of the atmosphere will be arranged in strata parallel to the earth's surface. The lowest stratum will be the warmest, the highest the least warm. The transition from the temperature of one stratum to that of the next will be gradual and regular. The changes of moisture and of density in the various strata will be gradual and not abrupt.

A ray of light from a star falling on such a series of strata will pass through them all in a regular smooth curve. In the telescope no twinkling of the star-image will be noticed.

Now if some of these strata are very cold, while the adjacent ones are warm, the atmosphere in such regions will be in rapid and irregular motion. The warm air below will be rising through the cold strata above and the air of the latter will be falling. These motions are necessarily irregular and complex. If a strong wind is blowing in these regions, the rapidity and complexity of the changes may be increased. A ray of star-light will pass through such a mixture in a zigzag line with a thousand small irregularities, and these will produce variations in the image seen by a telescope. Let us first consider the sidewise motions of the star-image. To the naked eye these may appear quite considerable. In the telescope they will be multiplied by the magnifying power used.

Beside the sidewise motion of the star-image produced as described, the motions of the layers of atmosphere give rise to other effects. They virtually change the focus of the observing telescope, as follows: The object-glass of the telescope is a lens which grasps parallel rays and brings them to a definite focus. The eyepiece is placed so as to see the image at the focus as sharply as possible. A change of a few thousandths of an inch in the position of the eyepiece may be fatal to good definition of the image. If we should suddenly change the object-glass of the telescope and replace it by another one of slightly different focus, say a few tenths or even hundredths of an inch different, leaving everything else the same, it is clear that accurate vision would be destroyed. A perfect image of the star would be formed in the focus of the new object-glass, but the eyepiece would no longer be in the correct position with reference to the new image, and the vision would be unsatisfactory.

An effect precisely similar to the sudden changing of object-glasses is frequently produced by the sudden changing of the curvature of the layers of air in front of the telescope. These layers, which were, let us say, at first horizontal, are suddenly bent by air currents so as to have a decided curvature and so that they act like lenses upon the incident star-light.

The ray from the star which at first came to the true focus of the glass-lens of the telescope is suddenly brought to a new focus, whose position is fixed by the combination of the air-lens, so to say, and of the glass-lens. Measures of the curvature of such atmospheric strata have been made, and their radii of curvature have been shown to be at least as small as 6600 feet. An air-lens of this curvature in front of the object glass of a large telescope will change the place of the image by several hundredths of an inch. The eyepiece, which remains at one place, can no longer give an accurate image, and the definition is thus spoiled.

The foregoing elementary explanation supposes the change of focus to take place with some regularity. In practice the changes are usually very irregular, so that, for example, it would be quite impossible to alter the position of the eyepiece to a place suitable for seeing the new image.

The twinkling of stars also produces marked changes in their colors. A bright star, near the horizon, will show these changes to the naked eye. In the telescope, and especially in the spectroscope, they are very obvious, and at times quite fatal to measurements. They are all due to changes in the temperature and arrangement of the strata of the atmosphere, and are only absent when these strata are arranged concentrically in parallel layers.

The deformations of star-images and of star-spectra have been studied by Arago, Secchi, Dufour, Montigny, and others, to whose memoirs reference is made in passing. The object of the foregoing paragraphs is simply to describe the general effects of bad definition—bad seeing—due to inequality in the distribution of temperature in the atmospheric strata in the neighborhood of the observer. These effects are more apparent the larger the aperture of the telescope employed and the greater its focal length.

More bundles of rays, coming from more directions, fall upon a large object-glass than upon a small one. The changes in focal length due to "air-lenses" are expressed in per cent of the focal length itself, and hence the absolute displacement of the disturbed image, in inches, is greater when long telescopes are employed. It is for these reasons that it is especially necessary to select suitable sites for the emplacement of the large telescopes of modern times. The study of the conditions of seeing at mountain observatories thus becomes of capital importance.

In a general way it may be said that the air-strata over an extensive plain arrange themselves horizontally. On a mountain peak, however, they are necessarily curved, except when a complete calm prevails, and when, also, the temperature-conditions are the same for considerable distances above and below the peak, if the whole air is clear, or from a considerable distance above the peak down to the upper surface of an extensive fog-layer itself lying some distance below the summit. The last arrangement describes the usual summer conditions at night on Mt. Hamilton. A capital merit of our climate is that the vision usually continues good during the entire night if it is good at the beginning.

An important advantage to be sought for in the site of an astronomical observatory is the *continued* clear weather. Much time is spent in preparing for observations; and this is time lost if the observations are prevented by clouds or fogs. If one is sure of good weather, a programme of observation may be made weeks beforehand, and carried out to the letter at the appropriate time.

The observatory of Algiers probably has fewer clouds than any other. In 1883 the sun was photographed there on 310 days.*

Southern California, Egypt, Arabia, Madeira, Peru, parts of Australia, etc., have excellent records in this regard; not all of these regions are suitable for refined astronomical observations, however, as several of them fail in respect of the most important condition, namely, steadiness of the air.

The advantage of a suitable station for astronomical work can be strikingly illustrated by a comparison. Dr. Lewis Rutherfurd made hundreds and hundreds of negatives of the moon, only a few of which are of high excellence, the sole cause being the very unfavorable situation of his observatory in the city of New York. Dr. Henry Draper, in 1877, reported that only three nights in two years gave him good lunar photographs at his observatory at Hastings-on-the-Hudson, where the steadiness of the air was not satisfactory.

During August, 1888, photographs of the moon were made at Mt. Hamilton on the following dates. All the negatives were fairly good and those marked with a star were very good; with two stars, excellent: August 12*, 13*, 14**, 15**, 16, 17, 18, 19 (no observations—Sunday), 20, 21, 22, 23*, 24*, 25, 26*, 27*, 28*, 29 (no observations—the sky was clear), 30*, 31*.

All the nights were clear—nearly all were good—and at least two of them were superb.

Speaking broadly, and making every allowance for exceptions, it is true that, other things being equal, an astronomical station on an extended and elevated plain is preferable to one on a sharp peak. The conditions for level and tranquil arrangements of air-strata are more favorable in the former case.

In any case, it is desirable that the surroundings of an astronomical observatory should be uniform—homogeneous. The level verdant plains of Lombardy, the small coral islets of the tropics of the Pacific, are examples. A level extensive plain of snow is not, in itself, objectionable; but such plains are ordinarily found in regions affected by other conditions which are distinctly unfavorable.

High rocky peaks will usually have bad vision both night and day, owing to the heating of the rocks by day and to the air-currents (controlled by the topography) by night. In regions (like California) where the air is very dry, and where there is no great diurnal variation in temperature (as on the flanks of Mount Whitney, and elsewhere in the Sierras), the conditions for good vision are very frequently present. I should suppose, however, that they would vary very much

* *Publications of the Astronomical Society of the Pacific*, vol. IV, p. 268.

from one locality to another, though this does not seem to be the judgment of Professor Davidson, whose experience is very wide in this respect.

In the Rocky Mountains of Wyoming, Utah, and Colorado, speaking generally, and also at such stations as Mont Blanc, it would seem that excellent observing weather would be rare (especially in respect of steadiness).

It must be borne in mind that the uses (to astronomy) of high-level stations are, in general, not for consecutive and long-continued registration of phenomena, but rather for comparison between the results of special observations made simultaneously, or nearly so, at high and low levels. In most researches these corresponding series may be short, and do not require the expensive installation of a permanent observatory, but rather the equipment of a scientific camp, and this is especially true if suitable stations are selected.

It is also necessary to look at the question in a practical way.

The available endowment of astronomical research is, in fact, limited. Certain large subsidies are, and always will be, granted by governments and they may, in the future, be greatly increased. The generosity of individuals, like Lick, Boyden, Bischoffshcim, Draper, and others, seems unbounded; but there is a limit to this, as well.

The practical question to be decided is, how shall these endowments be best expended for the benefit of astronomy?

It is certain that, in future, no one will be justified in establishing an astronomical observatory of research in a site which has not previously been proved to be suitable.*

High-level meteorological observatories will always be needed, in spite of the fact that their records are necessarily much affected by merely local conditions. The improvement of self-registering instruments, running for long periods, will enable such establishments to dispense with a large staff of observers.†

The development of methods of observing by instruments in balloons

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*The great apparent waste of money in the establishment of new observatories in the United States may be partly justified by the fact that most of them are attached to colleges, and are directly useful in training students in exact methods. Founders of such establishments will do well to recollect that comparatively small and inexpensive outfits will accomplish all the ends of a college observatory. Ten thousand dollars wisely expended is sufficient, and twenty thousand dollars will provide an observatory in which original work can be well done. The important point is to provide an endowment fund, to be used solely for scientific work, over and above the first cost of the establishment.

† M. T. de Bort (*American Meteorological Journal*, vol. VII, p. 319,) expresses the opinion that $1000 to $2000 will provide the outfit for a station of this sort, and that its annual expense need not be over $200. The site chosen will, of course, greatly modify these estimates.

and on kites will do away with the necessity for a great number of mountain stations. A given amount of money expended in securing such observations will, without doubt, produce the maximum of useful result.

It is important to remember that observatories on high mountains, as at Etna, must either be abandoned altogether during the winter season or, if occupied, the observer must be subjected to extremely trying conditions and to some danger from terrific storms of wind, snow, hail, from lightning, etc. The discomfort and monotony of such a life, subjected to very low temperatures and surrounded by clouds and snow for long periods, will unfit an ordinary individual for making the best use of the few clear days which an alpine winter presents.

Telephone and telegraph lines cannot be maintained in working order under such conditions without taking extraordinary precautions, and there must be days and weeks together when travel between the summit and the valley is shut off.*

Some of the material hindrances in the case of mountain-stations are:

1. The great expense of erecting suitable and safe buildings at such sites. The cost of building (M. Vallot's observatory) on the flanks of Mont Blanc was $74 per cubic metre.

2. The large cost of maintenance.

3. The difficulty in arranging for an adequate water-supply.

4. The great expense for freight. Transportation to the summit of Mont Blanc costs 2.50 francs per kilogramme, or about 23 cents per pound. Even at Mount Hamilton light parcels (food, etc.), delivered daily, cost 1 cent per pound; and heavy freight hauled from San José, as occasion serves, costs $8 per ton.

5 *Forest-Fires.*—Observers upon mountains in the United States frequently report that the smoke from distant forest-fires is a great hindrance to their work. The transparency and purity of the sky are greatly affected by the smoke from a large fire, even if it is quite distant. Such hindrances will continue to be felt until the United States and the several States adopt a rational system of forest conservation. The waste lands are occupied by sheep-herders, and fires are deliberately set by them so as to insure a better crop of grass for the next season. In more settled regions, as near Mount Hamilton, forest-fires are usually the result of carelessness and accident, but they are frequent.

6. *Snow-Blindness.*—Snow-blindness is a severe and sudden attack of inflammation of the eyes. A few hours' use of the unprotected eyes

* Even on Mount Hamilton we have been without any communication with the valley for a week, and without stage communication for three weeks. And Mount Hamilton winters are a *bagatelle* to the summers of Mont Blanc.

may bring it on. The application of suitable lotions will cure the actual blindness in a day or so, but the eyes remain tender and weak for long periods after a bad attack, for weeks or even months. It is necessary to wear tinted spectacles if one wishes to avoid this painful and troublesome experience. This is an inconvenience connected with life at high altitudes which cannot be avoided except by special precautions.

7. *Mountain-Sickness.*—Considerations on the so-called "mountain-sickness" will be found in various places throughout this paper, in connection with narratives of residence or adventure at high stations (see the sections on Whymper's travels in the Andes, the Harvard College stations in South America, Mont Blanc, etc.).

It may be noted here that some two-thirds of the tourists who come (by train in 1¾ hours) from the level of Manitou (6563 feet) to the summit station of Pike's Peak (14,115 feet) are affected by the altitude, though they have made no physical exertion whatever.

Some of the cases are serious. Certain persons are not able to remain on the summit at all.

Mountain-Sickness on the Jungfrau.—The following item was found in California papers early in 1895:

> The proposed railway to the top of the Jungfrau, which is 13,671 feet high, has made it desirable to determine the effect upon employees and passengers of travel to so elevated a station. M. H. Kronecker, who has conducted the investigation, concludes that mountain-sickness sets in at altitudes varying with different persons. Beyond 10,000 feet it attacks all persons on the slightest muscular exertion, but children and very old people are much less subject to it than others. It varies with the character of the mountains, being usually less serious on isolated peaks. Persons in good health can stand passive transport to the height of the Jungfrau without inconvenience, but they should not remain more than two or three hours, as a prolonged stay might prove disastrous. Workmen should be carefully selected, and, if possible, acclimatized or frequently changed between stations; and the summit station should be so arranged that full benefit of the view may be had without effort.

If these statements are correct, it would seem that the *change* of barometric pressure, rather than the absolute pressure, is the immediate cause of mountain-sickness. In Switzerland, persons going from a low level, Interlachen, 1900 feet, up to 10,000 feet are said to be affected. It is rarely felt in the Rocky Mountains under 14,000 feet; but here the traveller has previously been living at an altitude of say 6000 feet. In the Andes, where the mountains often rise from high plains, the sickness seems to be first felt at about 16,000 feet, say 8000 feet above the lower stations.

I am informed by those who have lived among the Indians of the high Sierras of Chile that they are entirely exempt from mountain-sickness, and, in fact, that they do not appear to experience any inconvenience whatever from the thin air of great elevations. It is very noticeable that their chests and the upper part of their bodies are disproportionately large, and their lung-capacity far greater than ordinary. Europeans do not, however, acquire immunity by long residence.

8. Finally, the physical condition of persons living at high altitudes is best described in the words of M. Vallot as "diminished living." De Saussure says of his experiences on Mont Blanc that at the summit he could not accomplish in four and a half hours the work he had been used to do in less than three hours at the base. This is a kind of numerical measure of the falling off of ability.

A long experience in such residence or in mountaineering habituates one to the new conditions more or less, and the "living" is "diminished" in a less degree. The effect remains, however, and must be reckoned with in arranging for the occupation of high stations.

Devoted men can always be found to undergo necessary hardships in the pursuit of scientific truth. If the scientific results do not justify the exposure, we no longer admire the effort as devotion, but blame it as foolhardiness.

Following this introduction is a series of chapters dealing with the high-level meteorological and astronomical observatories of Europe, North America, and South America. In these chapters the subjects treated in the introduction in a general manner are again considered, more minutely, in connection with the particular conditions which subsist at the different stations. The main scientific and practical conclusions to be drawn from the facts here brought together are very plain and obvious.

Briefly they show the necessity for a careful examination of the sites proposed for an astronomical, or meteorological, observatory before a final choice is made. They prove that while some mountain-stations present great advantages for astronomical and astrophysical observatories this is by no means the case for all. And they point out that the more frequent use of balloons, etc., in meteorology is likely to result in a rapid advance in our knowledge of the physics of the atmosphere, and to do away, in a great degree, with the need for permanent meteorological stations at high levels.

It appears that different researches require different conditions. All would be best done at a station where both steadiness and transparency were absolute. But some can be very well performed under less perfect conditions, If one is searching for the site for a new observatory, both conditions should be insisted upon; if one is planning work at a station already established, the work should be chosen so that it can be well done under existing conditions.

None of these and other obvious conclusions are new. The mass of evidence will, however, bring new conviction even to those most familiar with it; and it may serve as a check on the wasteful expenditure of public and private endowments. The subsidies to science, great as they are, thanks to the generosity of governments and of individuals, must be carefully husbanded if we are to exploit its entire domain, which is enlarging day by day, one may say moment by moment.

CHAPTER I.—THE OBSERVATORIES OF EUROPE.

THE TENERIFFE EXPERIMENT (1856).

Professor C. Piazzi-Smyth, late Royal Astronomer for Scotland, deserves the lasting gratitude of practical astronomers for his undertaking of the Teneriffe experiment in the year 1856. The question of "how much astronomical observation can be benefited by eliminating the lower part of the atmosphere" was for the first time plainly put and partially solved. In two works, one the scientific report of his expedition to the Royal Society of London,* the other more popular, † the question was stated in the plainest manner, and a partial conclusion was reached. I refer to the original works, just cited, for the history of the idea, which appears to have been entirely original with Professor Smyth, and only remark in passing that the expedition to Teneriffe was undertaken by the aid of a government grant, with the benefit of the advice of several distinguished astronomers, among them Sir George Airy and Sir John Herschel, and that it was greatly aided by Robert Stephenson, the Engineer of the Britannia Tubular Bridge. So much should be said in even the shortest notice of the expedition.

The summer of 1856 was spent at Teneriffe, and the instruments were set up at two stations, Guajara (8903 feet) and Alta Vista (10,702 feet). The summit (12,198 feet) was also visited. A little over two months was devoted to the work. A telescope of 7¼ inches in aperture was employed. The conclusions of Professor Smyth were briefly as follows:

With increased altitude (comparison of Teneriffe with Edinburgh) the *transparency* of the air was much improved (as was expected); and its *steadiness* also. (Teneriffe is a small island in the trade-wind belt, and the surrounding ocean should tend to equalize temperature and to produce *good definition.*)

The definition appeared to be equally good over all parts of the sky, and for the whole night, except shortly after sunset. During the daytime "the sun was seldom well defined." The blueness of the sky, even at the highest station, was in no wise remarkable. A "glare,"

* *Philosophical Transactions*, vol. CXLVIII, 1858, p. 465.

† *Teneriffe,—An Astronomer's Experiment.*

produced by reflection from dust particles, appears to have been generally present.

A very interesting observation of Professor Smyth may be mentioned in passing. Teneriffe is a volcanic island, and its craters were a living model of corresponding formations in the moon, even to small details of structure. (The same is true of Hawaii.)

Professor Smyth refers to the uncommon dryness of the air at the high stations as an "agent in producing good definition." The upper air was usually dry, and very frequently strata of clouds hung on the skirts of the mountain far below him. I am strongly inclined to believe that these clouds materially aided good definition by confining heat-waves from the mountain and sea from rising above them. Our best nights at Mount Hamilton appear to be those where mists and fogs cover the valley beneath us.

The steadiness of the stars to the naked eye was frequently remarked upon. They did not seem to twinkle, at first sight, though a careful view showed that they did so. This simple observation is the best evidence of the excellence of the observing-station.

The high *winds* in the trade-wind belt were felt as a practical inconvenience. Their effect upon the "seeing" is not mentioned by Professor Smyth. It cannot be favorable, in general, at mountain-stations, where the air in windy weather can never arrange itself in approximately horizontal strata. On extensive plains and at sea the effect of high winds on the seeing is, on the whole, good, according to my personal observation.

The *dust-haze* was ever more or less present, though sometimes in vastly greater quantities than at others. The "glare" near the sun was directly due to this. It lay in horizontal banks. An observer at the level of the sea would be more incommoded by such a bank than one at a higher station if he were looking nearly vertically. But it might be different for a nearly horizontal view if the higher station lay in the plane of the bank. A sharp rain will always settle such dust-banks, but at Mount Hamilton it almost always leaves the air unsteady.

The transparency of the air was extremely favorable for certain physical observations, as of the zodiacal light, solar radiation measures, spectroscopic and polariscopic observations, etc. It is, in fact, obvious that the mere avoidance of the lower strata of the atmosphere must be of the highest value in certain work of this kind, and that any mountain observatory will have *certain* advantages. Definition is important to the astronomer, but there are many physical problems in which it plays no part. All these points, which are simple, were first brought out in a clear and definite fashion by this expedition. Teneriffe may be regarded as the parent of every mountain observatory.

The Astronomical Observatory on Etna (9652 feet).

The observatory on Etna was first proposed by Professor Tacchini, in June, 1871, although his idea was not realized till 1881. As at present organized, it is an annex of the observatory of Catania. The 35 *cm.* (13.8-inch,) equatorial of the two observatories has a single object-glass and two mountings, one at each station. During the favorable season, July to October, the lens is mounted at the summit, while it is employed at Catania for the remainder of the year. The Etna station is reached by a drive of about eleven miles over a carriage road to Nicolosi, and from thence on horseback in six hours, provided the trail is not obstructed by snow.

Several important series of observations, having for their object the determination of the relative advantages of high-and low-level observing stations, have been carried out on Etna by Tacchini, Langley, Hale, Ricco, and others. They need not be referred to in detail here. The detailed report of Professor Hale and the general conclusions of Professor Tacchini, which follow, seem to give all the information of special value for our immediate purpose.

Professor G. E. Hale spent some time on Etna in 1894 in an attempt to photograph the solar corona in full sunshine. His notes on the purity of the sky show that the blueness of the sky increased slightly from 1450 metres (4757 feet) up to the summit. The stars were unsteady even at the zenith (July 8).

On July 9 the sky was clear. A strong wind was blowing the smoke from the great crater (which rose behind the observatory to an altitude of 3312 *m.*, 10,866 feet) away from the direction of the sun. Half the island of Sicily was dimly visible through a great brown bank of thick haze, the upper surface of which seemed to be nearly on a level with us. The sun was seen (between clouds) to be surrounded with a bright halo. In the afternoon the sky became much whiter.

On July 10 the wind blew the smoke of the great crater over the sun, making the sky very white. The image of the sun was rather better than at Catania, but it became unsteady later. At 10 h. the sun was surrounded by a white halo, and clouds of insects were noticed as at Pike's Peak in 1893.

July 11. The sky was very white with a bright ring around the sun. The seeing was excellent.

July 12. The sky was very white, and there was a bank of haze above the level of the observatory. The smoke from the crater was blown over the sun. The sky seen from the summit of the great crater was bluer than when seen from the observatory. The whole island was enveloped in haze. The seeing (at night) on the moon, *Saturn*, and stars was magnificent. The images were almost perfectly steady with the highest power. With the naked eye the twinkling of the stars was hardly perceptible in stars higher than 30°.

July 13. Sky cloudless and generally whitish, but the best seen since July 9. Much dust. The definition on the sun was poor.

July 14. The whole eastern sky was white. Left the observatory this day.

These notes of Professor Hale's seem to show that the smoke from

FIGURE 1:—THE ASTRONOMICAL OBSERVATORY ON THE SUMMIT OF ETNA, (9,652 feet).

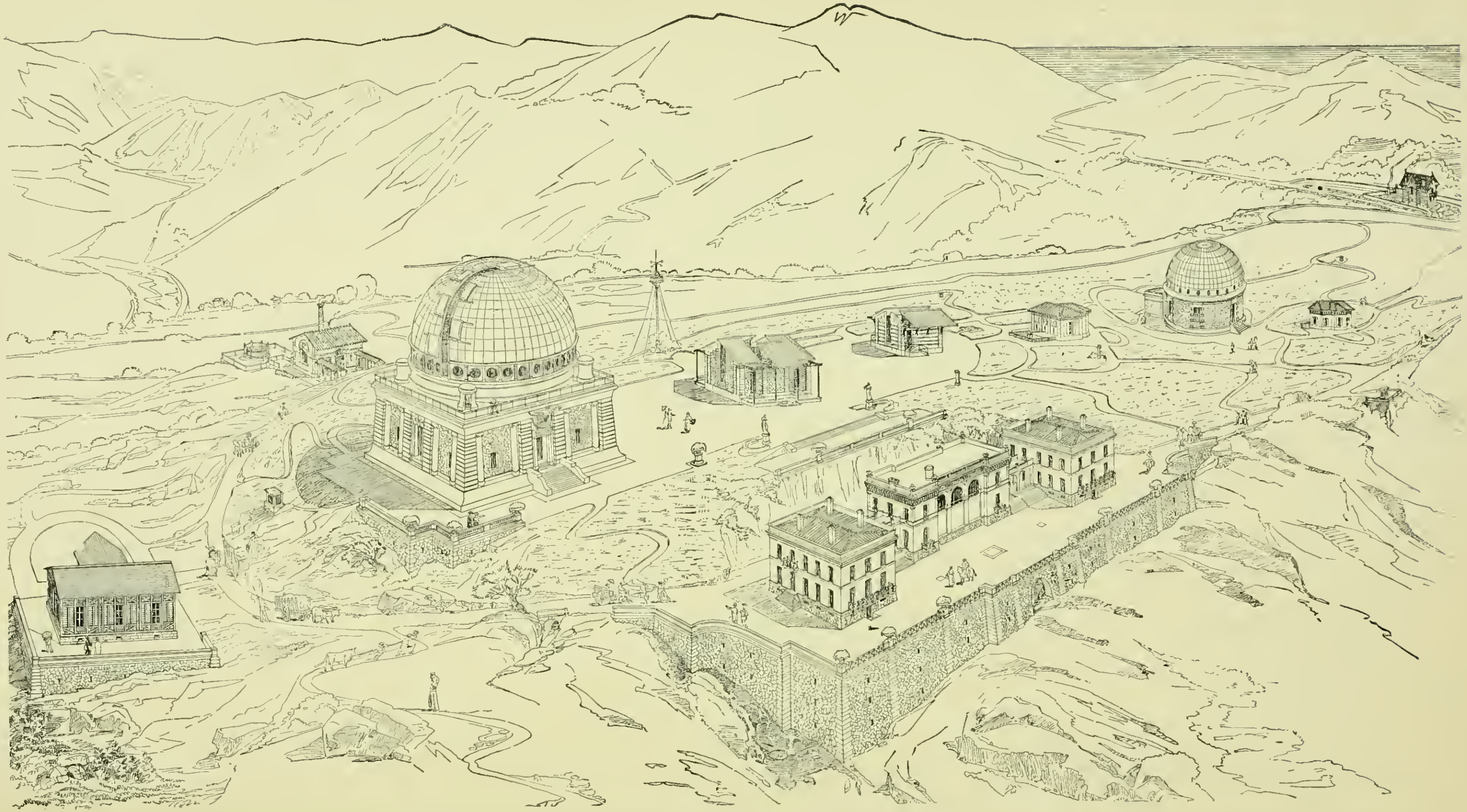

FIGURE 2;—THE ASTRONOMICAL OBSERVATORY OF NICE, (1,100 feet).

the crater produces a whitish sky, as is *a priori* probable. On one occasion the definition was of high quality. It is Professor Hale's opinion that the sky at Pike's Peak is considerably more pure; and this, again, is *a priori* likely to be the case. The forest-fires and the dust from the plains to the east and from the South Park to the west would seem to be the chief sources of solid particles in the surrounding air, and all these taken together are not likely to produce as much effect on the transparency of the sky as the smoke from Etna's crater.

The favorable season on Etna is comparatively short, from the middle of July till early October. The mean temperature of July at Casa Inglese (about 9600 feet above sea) is about + 5° C. (41°.0 F.), the highest is about + 13° C. (55°.4 F.), and the lowest about — 1° C. (30°.2 F.).

I have applied to my friend Professor Tacchini for his judgment of the astronomical conditions on the summit of Etna, and the paragraph which follows is extracted from his reply, dated January 23, 1896, to my letter of inquiry. This verdict must be accepted as entirely authoritative in all respects.

> "Quant à mon opinion sur les questions posées par vous, voilà ma rèponse :
>
> 1°. The sky is certainly markedly purer and more translucent on Etna than at the sea-level.
>
> 2°. The stars are markedly more steady on Etna than lower down.
>
> Mais, comme vous dites, suelement dans les meilleures conditions d'observation, qui, dans les observatoires très-élevés, ne sont pas aussi fréquentes comme on peut le croire."

The Astronomical Observatory of Nice

(ON MOUNT GROS, 1100 FEET ABOVE SEA).

The observers at Nice have been too much occupied with making valuable observations and discoveries to devote any considerable amount of attention to investigating the conditions of the atmosphere on Mount Gros, but their published volumes enable us to give a rough estimate of the steadiness of the atmosphere there. In the double-star measures of M. Perrotin with the 15-inch telescope, magnifying powers of about 1000 diameters were habitually used. Each measure of a star was marked *a*, *b*, *c*, according as the images were *good*, *pretty-good*, or *moderately-good*.

I have had the curiosity to count the number of times each letter occurs, as follows:

a	occurs	477	times,	from June, 1883, to August, 1886.
b	"	1282	"	
c	"	197	"	
	Total,	1956	"	

When the images were of class *c* it is obvious that few measures would be made. It is not necessary nor perhaps practicable, to deduce a numerical estimate of the average observing weather at Nice during this period for comparision with that at other observatories. It is obvious that the conditions are excellent, and distinctly better than at most observing stations.

Under good circumstances the transparency and purity of the sky at Nice are remarkable. If the disc of the sun be hidden by a screen there is no "glare" in the field even close to the point of tangency. For a time this transparency was lost, during the time of the Krakatoa eruption and the red sunsets, but it appears to be the normal condition. M. Thollon remarks (vol. II, p. E. 23) that the great comet of 1882 was seen by day from Mont Gros.

Mont Mounier (8993 feet).

The observatory of Nice, which was built by the gifts of M. Bischoffsheim, has an annex on the summit of the mountain *le Mounier*, 2741 metres (8993 feet) in altitude. The annex consists of a stone cottage for lodging the observer and his assistant, a metallic dome some 24 feet in diameter, covering an equatorial telescope of 38 *cm.* (15 inches) aperture, and a wooden store-house. The station is equipped not only for astronomical observations, but for meteorological as well; and it is connected by telephone with the neighboring village of Beuil. M. Perrotin describes the astronomical conditions as of the best.

Proposed Observatory on Mont Meige (Alpes dauphinoises) (13,000 feet).

It is proposed (December, 1894) to erect an observatory upon this high peak. I have no further information regarding it than the mere announcement.

Observatories, etc., on Mont Blanc (15,780 feet).

This is not the place to give even a *résumé* of the interesting history of Mont Blanc. It is necessary to confine this section to a bare recital of the main facts which bear on the question of its suitability for astronomical and meteorological stations.

So far back as 1760 the naturalist De Saussure offered a prize for the discovery of a practical route to the summit (15,780 feet), but it was not until 1786 that such a route was found by Balmat, the guide (and the ancestor of a family of guides).

In the next year De Saussure himself made the ascent and spent several weeks on the flanks of the mountain. Since that time many

FIGURE 3:—ON THE WAY TO THE MONT-BLANC OBSERVATORY.

ascents have been made, but none of them without difficulty and danger. A glance at the accompanying illustrations is instructive.

Mountain-sickness has been experienced on Mont Blanc by the great majority of climbers from the time of De Saussure until now. De Saussure found his powers of work much diminished. His words are: "Je ne pus faire dans ces quatre heures et demie toutes les expériences que j'ai fréquemment achevées en moins de trois heures au bord de la mer." Here we have something like a numerical estimate of the loss of physical vigor.

Such questions will soon receive a definite solution from the experiences of observers in actual residence on the summit.

The establishment of a meteorological observatory on the Pic-du-Midi and of stations at the Théodule pass (3300 metres) and on the Sonnblick (3100 metres), of late years, suggested to Monsieur J. Vallot of the French Alpine Club, that a station on Mont Blanc might be practicable and useful. In 1887 a party of thirty guides transported to the summit a tent and sufficient material to allow M. Vallot and three other persons to remain three days.

M. Vallot recognized the great difficulties to be overcome in establishing a station at the very summit, and therefore determined to erect a permanent meteorological station at the Rochers des Bosses (4365 metres, 14,321 feet).

It is M. Vallot's opinion that this station is preferable for meteorological purposes to one at the summit; and it is certainly far more accessible. M. Vallot's observatory was erected in 1890. In the same year, M. Janssen proposed to build an observatory at the very summit, and as a preliminary step did erect an observatory station at the Grands-Mulets (3000 metres, 9843 feet). The observatory of M. Vallot was erected at his own expense. The various stations constructed under the direction of M. Janssen have been built from a fund provided by subscription, and are, I believe, annexes of the Government Physical Observatory of Meudon, near Paris. Both these establishments pursue the most liberal policy towards scientific observers, and open their doors to any investigator; in fact, even to tourists and mountain climbers. M. Janssen's observations on the presence of oxygen in the atmosphere in 1891 were made from M. Vallot's observatory, and M. Janssen's establishment on the summit is to be international in character. This is certainly as it should be.

M. Janssen's Expedition to the Summit of Mont Blanc (1890).*

The original account of M. Janssen's scientific expedition to the summit of Mont Blanc is printed in the *Comptes Rendus* of the Paris Academy of Sciences,

* From the *Publications of the Astronomical Society of the Pacific*, vol. III., p. 50.

vol. CXI (1890). The following is a brief abstract. The object of the expedition was to determine whether oxygen exists in the solar atmosphere. When the solar spectrum is examined with a spectroscope, at sea-level, some lines are seen which may be due to oxygen in the sun's atmosphere, or which may be due to absorption effects in our own terrestrial air. If the spectrum is examined from terrestrial stations of great elevation, the absorptive effect of the earth's atmosphere is less and less, as the station chosen is higher and higher, naturally. In October, 1888, M. Janssen made the ascent of Mt. Blanc as far as the *Grands-Mulets* (about 9800 feet above the sea), and obtained satisfactory observations; in 1890 he ascended to the very summit of the mountain (15,780) feet, and repeated his work. The immediate scientific result of his two expeditions is that oxygen is not present in the gaseous envelopes which surround the sun; or, at least, if oxygen is present, it is in a condition entirely different from that known to us in our laboratories, and does not produce that absorption of light which is marked by the system of lines and bands familiar to spectroscopists.

This is a scientific conclusion of capital importance in questions of solar physics. It has been confirmed by later observations by the same observer on the summit of Mt. Blanc (1895).

The expedition of M. Janssen has an interest quite apart from its purely astronomical one. In fact M. Janssen lays the chief stress, in the paper cited, upon the question of the establishment of a high-level observatory at the top of the mountain, and points out the great scientific advantages to be gained from such an observatory devoted to questions of terrestrial as well as of solar physics. If such an observatory is to be founded anywhere it is tolerably certain that stations can be found which are far more favorable than Mt. Blanc. Pike's Peak, for example, is 14,134 feet high, and the summit can now be reached by a railway. There is no reason why a station on Pike's Peak could not be maintained throughout the year, since the U. S. Signal Service kept its observers there for several years continuously. There are also many stations in the Sierra Nevada of California which have natural advantages far above those of Pike's Peak. It would seem, then, that for scientific purposes alone, it might be better to maintain a station at one of these places (to speak only of mountains in North America), than to attempt to found such a station on the summit of Mt. Blanc, which can be reached only with great difficulty and some danger under the most favorable conditions, and which is practically inaccessible during many months of the year.

The chief interest in M. Janssen's paper, after its astronomical importance, is, for us, the exhibition of his intrepidity in planning such an ascent at all, and of his cool daring in accomplishing it. M. Janssen is sixty-six years of age, and suffers from a severe lameness, so that it is practically impossible for him to make continued exertion in walking. During his ascent to the *Grands-Mulets* in 1888 it was with the greatest difficulty and danger that he attained the cabin at that point, although the ascent is by no means difficult for good walkers. Many ladies, for example, go as far as this. How then was it possible for him to reach the summit, 6000 feet higher, which lies beyond a wilderness of huge rocks and great glaciers with their crevasses, and the route to which runs along steep *arêtes* only two or three feet wide, with terrific slopes on both sides of the narrow crests? To appreciate the splendid daring of M. Janssen, it is necessary to read his own words. It is only possible here to give the merest summary of them.

Before leaving Meudon, M. Janssen had a sled constructed which resembled in general pattern the reindeer sledge of the Laplanders. In front and behind this were double parallel cords, united by wooden rungs like ladders. A long line was attached to the front of the sled, and another to the rear. The ascent was made as follows: M. Janssen was seated in the sled, and twelve selected guides managed its movements. Two guides, far in advance, sunk an ice-axe in the snow as far

FIGURE 4:—ON THE WAY TO THE MONT-BLANC OBSERVATORY.

FIGURE 5:—ON THE WAY TO THE MONT-BLANC OBSERVATORY—(The Refuge at Grands Mulets).

as it would go and kept two turns of the forward line wound round its handle. When necessary the other line was kept tight also. The remaining guides pulled on the rope ladders front and back, or, when possible, supported the sled at the sides. In this way, foot by foot, the sled was moved. It was necessary for the guides to cut steps in the steep slopes for their feet to rest in. All that the passenger was required to do was to sit still and keep perfectly cool. This was all—but in the face of the frightful precipices with which the route is surrounded, it was enough.

There are few men whose nerves are steady enough to contemplate dangers of the sort when they are themselves precluded from some sort of physical action. I pass by all the incidents of the route ; the passage of the well-known obstacles ; the two days and a half spent in a small cabin at the station *des Bosses* during the prevalence of a hurricane ; the ascent of the final slope ; and simply recite that the summit was reached during weather exceedingly suited to the observations, and that the descent (which was more dangerous than the ascent) was safely accomplished. The party had been five days on the mountain.

M. Janssen says that he is perhaps the only person who has stood on the summit of Mt. Blanc without having made severe exertions to reach it, and who, therefore, was completely possessed of his intellectual vigor, which is always diminished after bodily toil. He makes no account of the nervous strain of the ascent, or of the anticipation of the far more dangerous descent, and this strain would be a more severe tax on the faculties of most persons than even violent and continued exertions. Those who remember M. Janssen's cool ride *on horseback* over the crater-floor of *Kilauea*, in 1883,* can understand that the danger of Mt. Blanc might seem a little thing to him ; but it is difficult to think that his plan for a physical observatory among those perils is a practical one. It is permissible to admire his courage and devotion, and yet, in the name of Science, to suggest that the dangerous summit of Mt. Blanc be abandoned for such a purpose, and that the proposed observatory be established on Pike's Peak, only a few hundreds of feet lower, at the end of a railway and telegraph line already in operation, and in a situation where it is perfectly practicable to maintain observers during the entire year, with few difficulties and with no peril ; or, if not at Pike's Peak, then at some station less dangerous than Mt. Blanc. Of M. Janssen's expedition and of his project we may be permitted to say, with the fullest admiration for his courage and for his successes, but with a recollection of the limitations of ordinary men—

"C'est magnifique, mais ce n'est pas la guerre."

M. Vallot's observatory is primarily devoted to meteorology and to observations of a physiological nature upon mountain-sickness and the effect of great heights upon the human frame. Vallot sums up his own experiences as follows: "Life at very high altitudes is not, like the living of a diseased person, the result of a disordered circulation, but it is rather a *diminished-living*, due to insufficient supply of oxygen."

The inhalation of pure oxygen appears to be, in some slight measure, a remedy for the effects of exertion at high altitudes.

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* Very likely this particular escapade of the venerable astronomer is unknown in Europe, though it is well remembered in Hawaii, and serves as a companion-piece to his escape from Paris in a balloon, during the Franco-Prussian war, in order that he might go to India to observe the eclipse of 1871.

M. Janssen has also made experiments on these physiological points. During his ascent of 1890 (just described) he was dragged to the summit on a sledge by guides without physical fatigue on his part, and he describes himself as entirely free from any ill effects due to the height.* *Exertion* at high levels seems to bring on mountain-sickness, however, unless one is habituated to them by long use, as Mr. Whymper's Andes experiments prove; and M. Vallot's expression of "diminished-living" must be true, in general, of those who have work to do at high altitudes—witness the guides and porters of the Mt. Blanc expeditions, to mention no others. The hundreds of visitors to Pike's Peak are subjected to no fatigue during their ascent in the railway train; but "two-thirds" of them are subject to mountain-sickness in spite of the absence of fatigue.

The main work of M. Janssen's stations is to be in the fields of astronomy, physics, and meteorology, although other researches are to be undertaken.

Stations on and near Mt. Blanc.

	metres.		feet.
Observatory at the summit (Janssen) (astronomical, physical, meteorological,)	4810	=	15781
Chalet at the Rocher-Rouge (Janssen)	4509	=	14793
Meteorological observatory at Rochers des Bosses (Vallot)	4365	=	14321
Chalet station of the French Alpine Club } Cabin of the Grands-Mulets }	3000	=	9843
Physical laboratory, etc., at Chamounix (Janssen)	1035	=	3396

The altitudes of other points on Mt. Blanc, are:

Rocher de la Tourette	4751 metres.
Rocher de la Tournette	4672 "
Petits-Mulets	4671 "
Petits Rochers-Rouges	4581 "

For comparison we may recall the altitudes following:

Geneva	407*m.* = 1315 feet
Grand St. Bernard	2477*m.* = 8127 feet

TABLE SHOWING THE WORK ON MT. BLANC FOR THE PAST TEN YEARS.

1886. M. Vallot made two ascents of Mt. Blanc.
1887. M. Vallot spent three days on Mt. Blanc.
1887. M. Vallot maintained self-registering meteorological instruments at Chamounix, Grands-Mulets, Mt. Blanc.
1888. M. Vallot made two ascents of Mt. Blanc.

* Pourquoi les émotions sont-elles alors si vives? pourquoi en particulier . . . éprouvai-je un sentiment de légèreté délicieuse dans tout mon être? pourquoi me semblait-il que j'étais soulagé d'un poids considérable qui avait jusque-là enchaîné et alourdi *ma pensée*, et que maintenant elle allait prendre son essor et aborder en toute liberté et amour les questions les plus difficiles et les plus belles d'un ordre moral supérieur? (*L'Astronomie*, 1893, p. 447.)

FIGURE 6:—VIEW OF MONT-BLANC, TAKEN FROM THE *BRÉVENT.*

FIGURE 7:—ON THE WAY TO THE MONT-BLANC OBSERVATORY—(Passage of a Crevasse).

1888. M. Janssen made spectroscopic observations on oxygen in the atmosphere at Grand-Mulets. (3000 *m.*)
1889. M. Vallot builds his observatory in Chamounix ready to be moved to the mountain.
1890. M. Vallot transports his observatory to Rochers des Bosses.
1890. M. Janssen proposes his observatory at the summit.
1890. M. Janssen makes a second series of observations on the presence of oxygen in the atmosphere, and ascends to the summit.
1891. The French Alpine Club places its observatory at Grands-Mulets.
1891. M. Janssen runs experimental tunnels in the snow at the summit, and places a small observatory there.
1892. M. Janssen constructs the observatory for the summit at Meudon.
1892. M. Janssen erects the Chalet at Rochers-Rouges.
1893. M. Janssen erects the observatory building at the summit (Sept. 8, 1893).
1894. Unfavorable season.
1895. The 12-inch equatorial carried to the summit and stored there. M. Janssen makes observations on oxygen in the sun at the summit.

Before erecting an observatory on the summit it was necessary for M. Janssen to know what sort of foundations his observatory was to rest on, and tunnels were run about 36 feet below the top surface of the snow at the summit without meeting rock. The temperature of the snow in these tunnels is nearly constant and about $-16°C. = +3°.2$ F.

The top of the mountain is, in fact, a glacier, and at times a *crevasse* has existed in the glacier near the summit. As no rock-foundations were available, M. Janssen determined to build his observatory on compressed snow, and to provide it with jack-screws in order that it may be levelled if necessary. The base of the structure is 10×5 metres and the snow always covers the lower story. It is intended to have the upper story in the free air, and to mount a telescope in an aluminium dome above the upper story. The construction is very solid and strong, with double walls and floors, and no pains have been spared to make it safe and rigid.

WEATHER ON MT. BLANC.

During August, 1891, a party of guides and workmen were employed in running the experimental tunnels at the summit of Mt. Blanc. An abstract of the meteorological diary is instructive. It should be compared with Professor Hale's diary on Pike's Peak.

15 August—work begun;

16 August—snow-storm; no work possible;

17 August—working;

18 August—working;

19 August—very heavy wind, no work; men go for provisions to Grands-Mulets.

20 August—very heavy wind, no work;

21 August—very heavy snow-storm; a tourist and a guide are killed by an avalanche;

22 August—violent storm;

23 August—snow-storm;

24 August—snow-storm;

25, 26, 27 August—the party goes to Chamounix for more workmen;

28 August—bad weather; no work done;

29, 30 August—working;

31 August—hurricane of snow; no work;

1 September—fine day; working;

2 September—working; Dr. Jacottet dies on the summit;

3 September—descent to Chamounix.

This, it must be remembered, is summer weather. The minimum temperature on the summit of Mt. Blanc during the winter of 1894 was $-43° C = -45°.4 F$.

The cost of buildings at these heights is very great. Ordinary laborers are paid 20 francs per diem when they are working near the summit, and 15 francs at the lower stations. The price for transporting one kilogramme to the summit is about 2.50 francs, or about 23 cents per pound. The ordinary load for a porter is about 12 to 15 kilogrammes (26-33 pounds), though some of M. Janssen's men carried from 28-30 kilos. (62-73 pounds). It is reported that the work on the observatories and stations built by M. Janssen has cost about $60,000, though this figure may not be correct. The building of M. Vallot erected in place cost about $9000, or about $74 per cubic metre.

The weather during the summer of 1894 was very unfavorable on the summit and the work was much interfered with. M. Janssen has devised an instrument (showing the records of a mercurial barometer, of the thermometer, hygrometer, and of the velocity and direction of the wind,) which is self-registering, and which will run for several months with one winding. This instrument is now ready for use. The difficulty of thickening oil in the works is overcome, but it does not appear how the traces of the different records (in ink? pencil?) are to be made. Even the best pens, etc., require frequent attention, especially at low temperatures.

In notes printed in the *Comptes Rendus* of September 2 and October 7, 1895,* M. Janssen describes the work of the observatory during 1895. The first communication is dated August 31, and reports that M. Bigourdan has determined the force of gravity at Chamounix and at the Grands-Mulets (3050 metres). The determination at the sum-

* And in the *Annuaire* of the Bureau of Longitudes for 1896, p. D 1.

IGURE 8:—M. JANSSEN'S OBSERVATORY AT THE SUMMIT OF MONT-BLANC, (15, 780 feet).

mit is reserved for 1896. The season was not favorable, and M. Janssen congratulates M. Bigourdan on the courage, activity, and devotion which he showed in the "rude campaign." Dr. de Thierry had also made a "difficult and courageous" ascent to the summit, where he stayed for an entire day, engaged in experiments on atmospheric ozone and on microbiology. Thanks to the courage, the force, and the experience of the porters, all the parts of the 12-inch equatorial which is to be installed at the summit have been transported amid "the chaos of the glacier" and stored in safety without an accident to the men.

Leaving Chamounix on September 26, M. Janssen himself made an ascent to the summit to engage in observations on the presence of water-vapor in the sun (which he found to be absent, all the conditions being favorable for his spectroscopic work,) to examine the storage of the parts of the equatorial, and to inspect the self-registering meteorological instrument (which had ceased to act because of lack of stability, and was corrected).

M. Janssen examined the observatory also, to determine whether it had suffered displacement since its installation. It has moved slightly towards Chamounix, but this movement took place in 1893–94. The construction can be levelled at any time by the jack-screws with which it is provided. The problem of building on the summits of high mountains is then in a good way of solution, and M. Janssen points out that the high and snowy summits of the Andes, Himalaya, etc., "actuellement si importantes pour les progrès de la Météorologie et de l'Astronomie," are open to occupation so soon as we have learned to place buildings and instruments upon them which are appropriate to the conditions to which they will be subjected. In a foot-note M. Janssen recalls the fact that in 1891 M. Vallot pointed out that the summit of Mt. Blanc was a true glacier, and that such a site for an observatory should be rejected. The whole history of the Mt. Blanc station is not yet written, and it is at least possible that the very ingenious arrangements for the foundations of the summit station, which are entirely satisfactory at present, may need modification at a future time, under changed conditions. The summits of high mountains are certainly liable to serious changes, as many observations have abundantly proved.

In a note of 1890, Professor Cornu describes observations made by Dr. Simony in 1888 on the peak of Teneriffe, which had for their object the registration of the solar spectrum by photography, and which have a bearing on observations to be made on Mt. Blanc. It is of importance to know what the limits of the solar spectrum are, and, on the other hand, the observation of these limits at different altitudes constitutes an excellent test of the purity of the sky at great altitudes, and gives a numerical measure of it.

From Professor Cornu's Alpine observations made in 1879, the result was that an elevation of 868 metres (2848 feet) increased the upper limit of the solar photographic spectrum by one unit of Angström's scale (*i. e.*, by one millionth of 1 *mm.*). The observations of Dr. Simony were made at two stations on Teneriffe, at Alta-Vista (10,702 feet), and at the summit (12,198 feet). Professor Cornu's map made at Courtenay (170 metres, 558 feet, above sea) served as a basis of comparison, and the comparison showed that the gain at Teneriffe in 1888 was substantially the same as that obtained in the earlier Alpine observations. Professor Cornu's conclusion is "that very little is to be gained [in this particular research] by transporting a spectrograph to high mountain stations; the amount of the gain appears to be less and less as greater elevations are reached." In spite of the small benefit, the great interest which attaches to the subject makes it very desirable that these experiments should be repeated at the summit of Mt. Blanc, "especially if the observer can remain sufficiently long at that great height."

PROPOSED RAILWAY TO THE SUMMIT OF MT. BLANC.

The scheme for a railroad to the summit of the Jungfrau has stimulated two or three eminent French engineers to propose the greatest of all tasks of this kind—namely, a railroad, or, rather, an elevator, to the top of Mt. Blanc. The line would commence at the Miage Ravine, above Saint-Gervais, and at once be carried through a tunnel four and a half miles in length. From this point a vertical shaft 9100 feet in height would bring the traveller to the summit. The engineers are not inclined to underrate the difficulties of the scheme. The height of the vertical shaft will be more than double any now in existence. It is said, however, that the road would not cost more than 9,000,000 francs.

It would be easy to quote from many accounts of ascensions of Mt. Blanc to show the real dangers which still remain and which always will attach to this journey. The latest account will serve the purpose as well as another—and in what follows I shall give a few paragraphs from Mr. Garrett Serviss' recital of his ascent to the summit in August, 1895. In early August Mr. Serviss ascended as far as the refuge hut at des Bosses, but was obliged to return on account of a terrific storm of snow and wind. The successful journey was made at the end of the same month. Two of the illustrations in this section are taken from Mr. Serviss' excellent article in *McClure's Magazine* for May, 1896.

On the tenth of August Mr. Serviss left Chamounix with a guide and one porter. M. Janssen, then at Chamounix, predicted that the weather was sure to be fine. As far as the Grands-Mulets the dangers are few, though the crevasses near the junction are sometimes troublesome and occasionally perilous. (Madame Marke and Olivier Gay were lost here in 1870.) The night was passed at the cabin at Grands-Mulets.

It is customary to leave the cabin for the ascent to the summit about midnight in order to pass the snow-slopes before the action of the sun has loosened the avalanches and weakened the snow-bridges over the crevasses. Mr. Serviss did not leave, however, until about 3.30 A.M. At the height of 12,000 feet one comes to the Petit Plateau, "a comparatively horizontal lap of snow which is frequently swept by avalanches of ice descending from the enormous *séracs* that hang like cornices upon the precipices above. It is one of the most dangerous places on the mountain. 'Men have lost their lives here and will again lose them,' is the remark of Mr. Conway, the Himalayan climber, in describing his passage of the place. 'Many times have I crossed it,' said M. Vallot, the mountain meteorologist, 'but never without a sinking of the heart, and the moment we are over the Petit Plateau I always hear my guides, trained and fearless men, mutter 'Once more we are out of it.' . . . Above the Petit Plateau is a steep ascent called the *Grands Montées* which leads to the Grand Plateau, a much wider level than the other, edged with tremendous ice-cliffs and crevasses and situated at a level of 13,000 feet." Here they were caught in a storm and quickened their steps; "it would not do to be caught here. The Grand Plateau has taken more lives than its ill-starred neighbor below." Here the party bore off to the right amid "a wilderness of snow and ice encompassed with precipices, chasms, and pitfalls, treading on we knew not what, assailed by a wild storm, all landmarks obliterated, and our foot-steps filling so fast with drifted snow that in two minutes we could not see from what direction we had last come." (It was here that Dr. Bean, Mr. Randall, Rev. Mr. Corkendale, with five guides and three porters,—eleven persons in all,—were lost in 1870.) A fortunate break in the clouds allowed the guide a momentary view of familiar rocks, and in due time they found the refuge hut at the Rochers des Bosses. The successful ascent was made on August 29. On August 18 three persons had ascended from the Italian side, and had perished in the crevasses above the Grands-Mulets (Dr. Schnurdreher, guide, and porter). Their bodies were found August 26 and brought to Chamounix. Mr. Serviss adds the gruesome remark: "Every boy in Chamounix understands how a body should be brought down from Mt. Blanc."

The ascent of August 29 was made by the Corridor, and the day was perfect. (See the plates.) With this we may leave Mr. Serviss' graphic recital. I have quoted it to show briefly the perils and difficulties of the ascent. Almost any one of a hundred other accounts would have served to show that the scientific achievements of the Mont Blanc observatory will have to be of the first order in order to compensate for the risks to human life which its establishment involves. Men have already died in its service, and more lives will be exacted by the inexorable conditions of this giant mountain.

When one considers that, in all probability, no scientific result will be reached on Mont Blanc which could not be attained on dozens of other peaks each accessible by railway or by entirely safe trails and at far less cost, it becomes a serious question whether the establishment of an observatory in this very unfavorable site is to be praised or blamed. In my own view there is no doubt that the same expenditure of energy and money would have accomplished a greater scientific benefit if a different site had been selected.

Atmospheric Conditions on the Riffel (8000 feet).

In the year 1886 Captain Abney made a short series of observations on the transmission of sunlight through the atmosphere, using the Riffel, Zermatt, as a high-level station.

His remarks on the atmospheric conditions at this station (*Phil. Trans.* R. S., 1887, p. 255), while interesting, are in entire disaccord with similar observations made at similar altitudes at other stations distributed all over the globe. He found little or no dust in the atmosphere, though we know that it is generally present at altitudes far greater than 8000 feet. The sky-spectrum was barely visible in a pocket-spectroscope. The sky was "blue-black." At this altitude in the Rocky Mountains, in the Sierras of California, in the Andes, on Etna, on Teneriffe, and on Mauna Loa, the two latter peaks being closely surrounded by the sea, the dust haze is almost always to be seen. The sky does not become "blue-black" until an altitude considerably greater than 8000 feet is reached. In the Rockies during three visits aggregating eight weeks or so, I have never seen the sky "blue-black" under 12,000 to 13,000 feet. It would appear that Captain Abney's observation was made under unusual circumstances.

The Riffel was occupied in 1884 by Mr. Ray Woods, but the circumstances were then specially unfavorable, and the sun was always surrounded by a "red haze."

Mountain Meteorological Stations of Europe.

Under this title and in the year 1886 Mr. A. Lawrence Rotch, Director of the Blue Hill (Meteorological) Observatory reprinted a num-

FIGURE 9:—THE METEOROLOGICAL STATION ON THE SÄNTIS (8,200 feet).

ber of interesting accounts of the high meteorological stations of Europe.

The highest German station is the Wendelstein on the northern slopes of the Alps near Munich. Its altitude is 1837 metres. The Säntis in Switzerland (2504 *m.*), the Rigi (1790 *m.*), the Great St. Bernard (2478 *m.*) are well known.

The most famous station in France is the Puy-de-Dome (about 1400 *m.*) where Pascal caused his barometric experiment to be tried in 1648; the highest station is the Pic-du-Midi (2877 *m.*). This station is particularly interesting to astronomers because its work is not confined to meteorology.* Reference should be made to Dr. Rotch's work by all specially interested in the meteorological services of such stations. Such of them as have been tested astronomically are spoken of in what follows.

THE METEOROLOGICAL OBSERVATORY ON BEN NEVIS (4368 FEET).

The summit of the Ben is a most unsatisfactory station for astronomical work. During 1893, for example, the average cloudiness of the year was 84 per cent; and in December, 1893, there was but a single hour of sunshine! The energies of the observers are, consequently, entirely devoted to purely meteorological observations.

The Meteorological Observatory on Ben Nevis had a serious experience in June, 1895. During a thunder storm, a flash entered the building, fused the telegraph wires, damaged several of the instruments, and stunned one of the observers, but fortunately did not kill him. In its passage the lightning set fire to the felt and timber lining of the building. Assisted by some tourists who had taken refuge from the storm, the observers succeeded in subduing the fire. In this connection, compare the journal of the observers on Pike's Peak.

THE METEOROLOGICAL OBSERVATORY OF THE SÄNTIS (8200 FEET).

Dr. Müller, of the Potsdam Astrophysical Observatory, spent a considerable time on the summit of the Säntis, engaged in photometric and spectroscopic observations. The former series was arranged so as to determine the absorption of the air and its effect in diminishing the visual brightness of stars. For our purposes we may quote some of his results as follows:

Stars between the zenith and 47° Z. D. showed $\frac{1}{10}$ of a magnitude brighter at the summit than at sea-level. As the zenith distances of

* The Mont-Ventoux station (6250 feet) cost about $40,000 to install; the Aigonal station (5150 feet) was established at about the same cost. I do not know the yearly budgets of these establishments, nor of the Eiffel Tower station (980 feet).

stars increased, their gain in brightness was proportionately more, so that at 88 ° Z. D. stars were a full magnitude brighter on the Säntis than at sea-level. In all of Dr. Müller's observations he noted the steadiness of the air, as well as its transparency, and it follows from his figures that the air was very quiet and the star-images free from twinkling.

It is difficult to make a comparison, but it would seem from an examination of the figures that the steadiness of star-images on the Säntis during these observations was considerably greater than the steadiness on Pike's Peak and in Colorado in the summer season, and materially less than that at Mount Hamilton during the months June-October. The comparison is, however, difficult to make with accuracy.

Dr. Müller's observations also related to a comparison of the solar spectrum at high and low altitudes of the sun, and thus determined the absorptive effect of a portion of the earth's atmosphere. It will be observed that the programme of Dr. Müller was concerned with problems whose solution must depend upon the comparison of observations at high and low levels. The permanent meteorological observatory afforded a convenient and comfortable station for his temporary wants. The first cost of the observatory was about 60,000 francs ($12,000), and its annual budget is 6000 francs ($1200).

THE METEOROLOGICAL OBSERVATORY ON THE SONNBLICK (9843 FEET).

From an account of the Sonnblick Observatory (3000 metres high) in *Himmel und Erde*, vol. iv, a few statistics of interest to astronomers are taken. The temperature-range (annual) is much less than at sea-level, being only 14° C. (25°.2 F.). For 100 metres' increase in altitude the temperature diminishes at the rate of $\frac{6}{10}$ of a degree C., but the rate diminishes with increasing altitude. There must be a point at which the summer and winter temperatures are alike—where there is no annual range. From the data obtained from the Sonnblick observations this height would be about 8800 metres (28,871 feet). There are, on the average, two hundred and fifty days of the year when the temperature is 0° C. or lower.

The sunniest months yet experienced at the Sonnblick Observatory during nearly seven years of observation are:

February,	1890, 205 clear hours	= 70 % of the maximum possible.				
September,	1891, 202	"	"	= 58 %	"	"	"
August,	1892, 227	"	"	= 52 %	"	"	"
July,	1893, 204	"	"	= 48 %	"	"	"

February, 1892, had only 48 hours of sunshine, and May, 1887, only 73.

FIGURE 10:—METEOROLOGICAL STATION ON THE SONNBLICK (9,843 feet).

FIGURE 11:—PANORAMA OF THE JUNGFRAU RANGE (Eiger, Mönch, Jungfrau).

There is eight times as much snowfall as rainfall at this station.

The twinkling of the stars is regularly observed on the Sonnblick, and it is found to be considerably greater than at the lower station.

The movements of the barometer; the wind pressures and velocities; the relative humidity; the formation and movements of clouds; the amount of atmospheric electricity; and all meteorological phenomena are daily observed on the Sonnblick, and these observations are employed in daily weather predictions. But their usefulness does not end here by any means, for the observations are thoroughly discussed and digested with reference to the fundamental problems of meteorological physics by the director of the Austrian Meteorological Service, Dr. Hann, and by his assistants. The first cost of this station was 6600 Austrian florins (about $3201), and its annual budget is 200 florins ($97).

ABASTOUMAN OBSERVATORY (TIFLIS, RUSSIA, 4600 FEET).

An observatory was founded in the government of Tiflis by the Grand Duke George of Russia, at an elevation of 4600 feet, and Professor Glasenapp has made many observations of double stars with its 9-inch equatorial. The station is now, I believe, abandoned.

MOUNTAIN RAILWAYS IN SWITZERLAND.

Since Switzerland has become the playground of Europe, mountain railways have already been constructed to various summits, and summer resorts established there. Science benefits by these experiments, for meteorological stations have been installed at such favorable points.

The Mt. Washington (6279 feet) mountain railway, opened in 1869, was probably the first of the kind. It is operated like all the early mountain railways by an engine with cog-wheel drivers. The railway up the Rigi (5741 feet), opened 1873, is on the same plan. The Mount Pilatus railway (6785 feet) was opened in 1888, and is again on the early plan.

Since the completion of the Pilatus railway a considerable number of others have been built or are in process of building. A number of them are cable roads, or electric trolley lines. The Mürren railway (1891) ends at an altitude of 5350 feet in face of the magnificent group of the Jungfrau (15,700 feet).

The Swiss government has authorized the construction of a combined railway and elevator which will land the traveller at the summit of this wonderfully beautiful peak and in the centre of a grand panorama; and it is understood that the government will subsidize the enterprise.

These matters, interesting in themselves, are of importance to science because it is now certain that high-level meteorological stations in abundance are soon to be available.

In our own country the railway up Mt. Washington has long been in operation, and the railway up Pike's Peak makes that summit available. A cable-railway to Echo Mountain (3500 feet) in California has lately been extended to Mt. Wilson (6000 feet). All these peaks have been, or will be, occupied as meteorological or astronomical stations. It is worthy of remark, in passing, that the rapid change of atmospheric pressure seems to be a cause of mountain-sickness for a large proportion of visitors to the summit of Pike's Peak, and even to some of the lower summits.

British India.

Hospitality is asked for a note in this place on a high-level observatory about to be established in British India.

THE KODIAKANAL SOLAR PHYSICS OBSERVATORY IN THE PALANI HILLS, INDIA (7700 FEET).

This new observatory, founded in 1895, is described by its Director, Mr. C. Michie Smith, in the *Publications of the Astronomical Society of the Pacific*, 1895. Its climate is utterly different from anything with which Europeans or Americans are familiar, as may be seen by a glance at the paper cited. There are over 2000 hours of sunshine yearly, and the experiments so far conducted show that the atmosphere is steady as well as clear. It is worthy of notice that very careful tests had been made of several sites before the site for the observatory was finally fixed.

FIGURE 12:—MT. CHACHANI, FROM THE AREQUIPA OBSERVATORY.

CHAPTER II.—THE OBSERVATORIES OF SOUTH AMERICA.

Dr. Copeland's Astronomical Experiments in the High Andes of Peru (1883).

During the early part of the year 1883, Dr. Ralph Copeland, now Astronomer Royal for Scotland, spent some months at high stations in the Andes for the purpose of testing their suitability for astronomical work. He had with him a 6-inch refractor and thus was able to make real tests. The principal stations occupied were La Paz (12,050 feet) Puno (12,608 feet) and Vinocaya (14,360 feet). At the latter place the sky was very pure during his first visit (March 1–16), and on the few occasions when the telescope could be used the definition was very good. At a second visit, June 5 to 27, there was a much greater proportion of unclouded weather, but on the other hand there was more dust in the atmosphere. At Puno, also, there was often dust in the atmosphere and the sky was milky from this cause. July to December is the unclouded season. Dr. Copeland's conclusions are that observing stations can certainly be found in the region examined that would possess great advantages over sites in Europe. Considering everything he seems to favor a medium elevation, say 12,000 to 13,000 feet, rather than a higher level. The whole report is of much value to astronomers.

Dr. Copeland remarks that the people who reside permanently at 14,000 feet elevation in these countries seem to be entirely healthy and to do a full day's work; and he makes the clever observation that the hammers in the machine shops at Vinocaya (14,360 feet) were as heavy as those used in England.

Mountain Stations Established by the Harvard College Observatory in Peru.

The astronomical station of the Harvard College Observatory in Peru is in the town of Arequipa (8060 feet). Fourteen miles from Arequipa is the mountain Chachani (20,000 feet) which is always snow-capped. A station has been established on the slopes of this peak 16,650 feet above sea-level. The ascent from Arequipa can be made on mule-back in about eight hours and the self-recording instruments of the station are visited periodically. Mountain-sickness, in some form, is almost invariably experienced by visitors. This high-level station is only a part of an extensive series of meteorological stations established by the Harvard College Observatory.

Another high-level observing station is on the summit of El Misti, 19,200 feet high. In February, 1894, the Misti was covered "with enormous quantities of snow." It is intended to establish other meteorological stations on the eastern slopes of the Andes, so as to make a thorough study of the climate from the Pacific eastwards.

A high-level meteorological station has also been opened at Cayalloma (15,500 feet) and 70 miles north of Arequipa.

The line of meteorological stations maintained by the Harvard College Observatory now (1895) extends from the coast, across the Andes, to the valley of the Amazon. They include Mollendo (altitude 100 feet), La Joya (4150), Arequipa (8060), Alto de los Huesos (13,300), Mt. Blanc station on the Misti (15,600), El Misti (19,200), Cuzco (11,000), and Santa Ana (3000).

Near Arequipa there are three very high peaks—Pichupichu (18,600 feet), El Misti (19,200), and Chachani (20,000).

In *Appalachia* (vol. vii.) Prof. W. H. Pickering gives a very instructive account of his ascent of El Misti, which is an active volcano, as has been mentioned. The Indian guides and porters, carrying fifty pounds, were not at all affected by mountain-sickness and kept in front of the best climbers of Professor Pickering's party. At 16,600 feet one of the party was obliged to give up the ascent on account of a severe attack of mountain-sickness. All the party were much affected at the last camp (18,440 feet). Professor Pickering and the guides alone reached the summit (19,200 feet) on the next day.

Mr. Waterbury, formerly of the University of California, was in charge of the meteorological instruments on El Misti, etc. (19,300 feet), till 1896. It was his duty to make the ascent once in ten days at least, and he has accomplished fifty-two such ascents. Most persons, he says, are greatly distressed by mountain-sickness at such elevations, but he "experienced little trouble." "Wind is always blowing on the mountain at a rate of 30 miles per hour; and the temperature ranges from + 38° to 0° F. The trip occupies two days, the first night being spent at a shelter station at 6000 feet. The rest of the ascent takes five hours. A bridle-path has been made after great difficulty, to the summit and mules now go to the top, the highest elevation that they have ever reached."

Professor Pickering has some further remarks on mountain-sickness as observed at a mountain camp on Chachani at a height of 16,600

FIGURE 13:—EL MISTI, FROM THE AREQUIPA OBSERVATORY.

feet in 1892. A hut was built here and a bridle-path led to it and a number of visitors went as high as this, riding on mules. It sometimes happened that a visitor would arrive perfectly well, and fifteen minutes later be completely prostrated. Recovery was sometimes rapid, but usually not so:

We found that all persons with blood of the white races in their veins were subject to the complaint, the pure-blooded Indians only being more or less exempt. Half-breeds who had spent all their lives in Arequipa were often more susceptible to it than ourselves. In my own case this susceptibility rapidly wore off and after my first night on the Misti I never again felt any very serious inconvenience.

Professor Pickering went to a height of 19,000 feet on Chachani without any premonitions of mountain-sickness.

The summit of this high mountain, Chachani, is said to have been reached by several persons, but there is no authentic record of such ascent until May, 1893, when Professor Schaeberle, of the Lick Observatory, in company with Professor Bailey, Mr. Duncker, and three natives, attempted the ascent. Professor Schaeberle and one native reached Little Chachani, a peak two or three thousand feet below the principal summit, the others being prostrated with mountain-sickness. From his report on the solar eclipse of April, 1893, the following notes are taken:

At the first camp (about 16,000 feet in elevation) the sky was not deep blue but hazy. A four-inch telescope was used at night on bright stars and the moon. "While the character of the images was less favorable than at Arequipa, the curious feature of very active commotion in the stellar image without any accompanying blurring, and the diffraction-rings, appeared much the same as at the observatory below. The moon's image also had the same woolly, surface-creeping look."

Professor Schaeberle's remarks on mountain-sickness are very instructive. One member of the party (Mr. Duncker) was seriously affected and became delirious. He reached a height of about 16,800 feet. On the next day Professor Bailey was obliged to give up the ascent at about the same elevation. The Indian guides were not in the least affected, either by cold or mountain-sickness; they ate freely and carried considerable loads. Professor Schaeberle's full and interesting report (*op. cit.*) should be read. He is of the opinion that it will always be impossible for observers to live and work at these great altitudes.

The main interest to astronomers in the Harvard College Observatory expeditions to South America is in the establishment of a well-equipped observatory at Arequipa (8060 feet). Here a large equatorial of thirteen inches aperture was installed in 1891, and it has been kept in full activity since that time. Every class of observing has received attention—double stars, observations of the moon, planets, and satellites, stellar spectra, photographic star-charts, zodiacal light observations, etc., and thus the materials for a judgment on the advantages of the station are at hand. Professor W. H. Pickering's conclusions are, in brief:

The transparency of the sky was such that it was a common occurrence to see third-magnitude stars set below the horizon where it was on the level with the eye.

With the 13-inch telescope ten and twelve diffraction-rings have been counted under favorable circumstances around the brighter stars, each ring being nearly if not absolutely motionless.

Powers of 1140 diameters have been used to advantage on *Venus* in the daytime, and the phases of *Jupiter's* satellites are seen as they enter the planet's shadow at eclipse. This phenomenon has probably never before been seen with a 13-inch telescope.*

The sky is always clear in the dry season, and during most of the mornings of the rainy season from November to April or May.

There can be no doubt that the astronomical observatory at Arequipa is far more favorably situated as to observing conditions than most permanent observatories. There is no question that its skies are more transparent, and the stars more steady than at fixed observatories in the eastern parts of the United States, for example, or than most observatories in England and on the continent of Europe. It is more difficult to obtain an accurate comparison between the steadiness of the atmosphere at Arequipa and at California observatories as Mt. Hamilton, Mt. Wilson, and Echo Mountain. The Harvard College Observatory maintained an observing station for some years on Mt. Wilson, and it is the verdict of the observers, I believe, that Arequipa is superior both in respect of transparent air and of steady definition. A few comparisons have been made by astronomers of the Lick Observatory between the conditions at Mt. Wilson and at Mt. Hamilton, with the general result that the best seeing at the two places is practically of the same excellence.† This would make the best conditions at Arequipa superior to those at Mt. Hamilton. A direct comparison between the two places was made by Professor Schaeberle of the Lick Observatory in 1893.

Professor Schaeberle stayed at Arequipa about two weeks (in the latter part of May), and with regard to the transparency of the sky ob-

* It is always seen at Mount Hamilton with the 36-inch equatorial.—E. S. H.

† Professor Barnard says of Mt. Wilson (July 18, 1892) that he has "nowhere seen a finer, clearer sky."

FIGURE 14:—ILLAMPU (the Highest of the Andes) AND THE SORATA RANGE, SEEN OVER LAKE TITICACA.

served that "the sky-glare was much more pronounced than it is at Mount Hamilton in favorable weather." Through the kindness of Professor Bailey, in charge of the observatory, opportunities were given to use the 13-inch equatorial visually. Professor Schaeberle (Eclipse-Report of April, 1893, p. 21) remarks that "the brighter stars were surrounded with many well-defined diffraction-rings,* which did not seem to be affected by the apparently great commotion in the stellar disk and rays—a curious kind of rapid twinkling without blurring. On turning to the moon I remarked that the seeing was 'woolly,' the effect of minute atmospheric waves plainly visible in the slight movements of the lunar surface. At the Lick Observatory the same quality of seeing would be classed about 4 on a scale of 5 for the best seeing." The conditions were regarded by Professor Bailey as excellent on the nights to which Professor Schaeberle refers.

Mr. A. E. Douglass, one of the astronomers of the Arequipa Observatory, has a few sentences relating to the conditions affecting the vision there in the *American Meteorological Journal* (vol. II., p. 395) as follows:

> The observatory is situated close to a river valley, down which, on clear nights, a swift stream of cold air descends. This frequently attains such a volume as to flow over the observatory grounds.
>
> When this cold air reached the [telescope] the seeing was immediately ruined. When this current once became established no more good seeing could be expected for the remainder of the night.

The foregoing comparisons between the best conditions of steady vision at Mt. Wilson, Arequipa, and Mt. Hamilton are interesting; they are probably not decisive. A comparison of the results of observation at the three places is difficult to make on many accounts. Another question of importance is the relative number of good observing nights (and days) at the three stations. This is a question which can be settled by statistics.

It is of considerable importance to obtain some definite notion of the relative excellence of observing stations in different parts of the globe. The main factor to be attended to is that of steady definition. It is known, to begin with, that a transparent air can be found in elevated regions nearly everywhere. For an astronomical station steady definition is much more important.

Where is this condition to be found? On Etna—in Egypt—in the

* Professor Schaeberle tells me that the expression "many" rings is correct. Professor W. H. Pickering says ten or twelve for bright stars under favorable circumstances. It is difficult to understand how many rings can be seen with a central disk which is quite unsteady.

Californian mountains—on the high, dry plains of Arizona—in Mexico —in the Andes—in Japan—or in which of these regions?

Wherever it is found, there is the place to install a large equatorial to be devoted to observations of the most difficult and delicate nature—to the settling of mooted questions—to discovery, in short. It is only in such situations that a great telescope will do full justice to its constructor and will afford the fullest scope to an accomplished and diligent observer.

Professor W. H. Pickering has been kind enough (in a letter of April 8, 1895), to give me a direct comparison between the astronomical conditions at Arequipa, Mt. Wilson, and Flagstaff, which he is better able to make than anyone else:

Regarding a comparison of the three observatories, Arequipa, Mt. Wilson, and Flagstaff, I think the sky was somewhat more transparent at the former, since fainter stars could be seen in the horizon. On the other hand I doubt if the difference was a practical one at altitudes over 30°. In fact, even at Cambridge, I do not believe there is very much light lost on a really clear night. The great advantage of the former stations, to my mind, was that the transparency was *the same* night after night, for perhaps a month at a time, so that similar observations, on comets for instance, could be conducted under identical conditions for considerable periods. I think there is no doubt that the moon appears whiter in Arequipa than in Cambridge, and the same remark applies, possibly in a less degree, to the two other stations. My only knowledge of the steadiness at Mt. Wilson is derived from photographs, and the statement of Mr. Lowell that on the night he looked through Professor Swift's telescope, which was said to be an average night, the seeing seemed to him to be about as good as at Flagstaff. Upon one or two occasions it seemed to me that the seeing at Flagstaff was as good as anything I had seen at Arequipa, but the difference was that while at Arequipa such seeing was common, at Flagstaff it was very rare.*

Still the average at Flagstaff was probably better than the best we have at Cambridge—it was certainly as good. My observations at Flagstaff lasted practically from June 1 to December 1. After the latter date there were many clouds and the seeing was very bad. Regarding the number of nights on which photographs could be taken, I am inclined to think that there was little to choose between the three places; perhaps 70 per cent of the nights were suitable. In Arequipa, however, the clouds were often very thin and of such a character that while showing structure they were not accompanied by bad seeing. Therefore upon these nights visual observations could be conducted upon bright objects, like the moon and the planets, and perhaps 80 to 85 per cent of the nights throughout the year could be so utilized.

One characteristic of Arequipa was that the seeing was excellent in the afternoons beginning at perhaps 4 o'clock. In the early morning, *i. e.* after midnight, the seeing at Arequipa was frequently bad.

This was apparently due to a local cause—the formation of a cold stream of air which followed down the river-bed from the interior. It is probable that at a site located a few miles back from the river this current would be avoided.

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* In making this statement I allow for the difference in the apertures of the Arequipa and Flagstaff telescopes. With the latter instrument one would necessarily be more critical.

FIGURE 15:—CHIMBORAZO, (20,545 feet).

Mr. Whymper's Expedition to the Andes of Ecuador.

The first sentence of Mr. Whymper's book propounds the question which his expedition to the Andes was intended to solve. "It has long been much debated," he says, "whether human life can be sustained at great altitudes above the level of the sea in such a manner as will permit of the accomplishment of useful work"—of useful scientific work, I understand him to mean. There is no question, he goes on to say, that it is possible to exist at great elevations for short periods. Balloon ascensions have fully demonstrated this fact.

Mountain-sickness has long been known to occur at altitudes above, say, 14,000 feet; and this in all parts of the world. Mr. Whymper's main object was to determine whether a prolonged residence at high altitudes might not do away with the depressing effects of mountain-sickness, and generally to study the physiological as well as the more practical aspects of the question.

De Saussure on Mont Blanc (15,780 feet) found himself unable to perform, in four and a half hours, the experiments for which less than three hours were sufficient at sea-level.

Darwin found it "incomprehensible how Humboldt and others were able to ascend to the elevation of 19,000 feet."

The brothers Schlagintweit ascended to great heights in Asia, and Mr. Whymper understands them to say that they became somewhat habituated to low pressures; although they also say that at heights of some 22,000 feet, it had become practically impossible to go farther, and that all the party was sick.

Mr. Whymper's plans pre-supposed that the experiments should be made by persons previously accustomed to mountain-work; that a prolonged sojourn should be made at elevations above, say, 15,000 feet; and that all discomfort should be eliminated so far as possible. Circumstances compelled him to select the high Andes of Ecuador as his field of work.

Mr. Whymper's own experience had been very wide, and his party included J. A. Carrel, an old Swiss guide, Carrel's cousin Louis, and a native of Ecuador. The first three were highly skilled mountaineers, and no one of them had ever been affected with mountain-sickness in the least degree. Their work had, however, all been done at elevations less than 16,000 feet. They reached their very first camp on Chimborazo (16,664 feet) by riding on mules. Mr. Whymper, at least, had not made any very severe exertion, yet he and both the Carrels were at once attacked with the mountain-sickness.

The party stayed on Chimborazo, at this time, for 17 days. One night had been passed at 14,375 feet, ten at 16,664, and six others at 17,285 feet. The summit was reached once (20,545 feet) and three times Mr. Whymper went to a height of 18,528 feet. Mountain-sickness had been experienced by all at a height of 16,600 feet; but "in course of time the more acute symptoms disappeared," though only a slight decrease of pressure could be sustained without bringing it on once more.

The volcano Cotopaxi (19,613 feet) was next attacked, and a camp was established at 15,139 feet altitude. Twenty-six hours were passed at or near the summit, and during this time there was no recurrence of the mountain-sickness which had been so marked on Chimborazo. Mr. Whymper remarks especially that there was no work to tax their strength, and says "it is by no means certain, if larger demands had been made upon it, that our condition would have remained equally sound."

After ascending various peaks, Antisana (19,335 feet), Cayambe (19,186 feet) among them, Chimborazo (20,498 feet) was ascended a second time without experiencing the *acute* symptoms of mountain-sickness. Something like seven months had been spent at high altitudes, and the party had become habituated to low barometric pressures.

Mr. Whymper devotes some twenty pages of his book to a discussion of his observations upon mountain-sickness. A small part of these observations has been summarized in what has gone before.

The important question is, can one become accustomed to low pressures, so that work can be accomplished at high altitudes with about the same facility as at lower ones?

Mr. Whymper's conclusion from all his experiments is that "we became *somewhat* habituated to low pressures," but he at once limits this statement. A crucial experiment showed that he himself, a skilled mountaineer, was "materially affected by and weakened at a pressure of twenty-one inches (9850 feet)."

Certain effects—increased circulation, fever, and general illness—were transitory, and disappeared after the explorers had become accustomed to great heights. These are the *acute* symptoms of mountain-sickness, and Mr. Whymper supposes them to arise from the difference of pressure between the external air and the internal gases of the body. In time an equilibrium is brought about, and the acute symptoms disappear.

Other effects are permanent so long as the person remains at a low pressure. These are chiefly due to a great increase in the rate of respiration. At rest, it was not too difficult to maintain life by increasing the volume of air inspired. The least exertion, however, made it extremely difficult to inhale sufficient air. Mr. Whymper examines the proposal of M. Paul Bert to inhale oxygen, and shows that however useful this may be for persons who pass rapidly from

FIGURE 16:—CHIMBORAZO FROM A POINT 17,450 FEET ABOVE SEA.

high to low pressures it certainly would have been of no service in his own experience.

Finally his conclusions are that ascents should be made gradually, so as to avoid the *acute* symptoms above mentioned; but that it is and will always be impossible for persons to live at extreme altitudes without a great loss of muscular powers. The question of a corresponding loss of mental alertness he does not examine. (See in this connection the remarks of M. Janssen, page 24, note.

The heights of the mountains climbed by Mr. Whymper are materially greater than that of the highest peak in Europe, but it is to be remarked that Mr. Whymper's experiments prove that even at comparatively moderate elevations (9,850 feet) he was "materially affected and weakened," and this at a time when he was in the best of training. The conclusions bear directly on the main question of this book. It is clear that the generality of persons can become habituated to low pressures so as to escape all the acute symptoms of mountain-sickness; but if Mr. Whymper's conclusions are to be relied upon it is not possible to live at elevations of 10,000 feet or so without losing a considerable part of one's normal muscular powers. At elevations of 15,000–16,000 feet this loss will be very considerable.

Boussingault, in his account of the ascent of Chimborazo (1831), speaks of all his predecessors in the Andes as having been much affected with the mountain-sickness. For himself and his companion, Colonel Hall, thé case was different. No acute symptoms were felt, which he attributes to the fact that they had lived for a long period at very great elevations. He notes the fact that the inhabitants of cities in the high Andes (Bogota, Potosi,* etc.) at 2900 to 4000 metres are not so affected, and describes balls in these cities where the young women dance the whole night, just as in Europe; bull-fights in Quito; and a pitched battle at Pichincha, which is about the height of Mont-Blanc. The fighters, men and bulls, were equally affected by the height, and their combats may not have been up to a European standard; but the dances are conclusive! The best evidence on the subject, however, comes from Dr. Copeland, who found the hammers in a machine shop in the Andes (14,000 feet) of the same weight as those at home in England. All the evidence shows that the natives of the Andes do not suffer materially at high elevations, even up to 19,000 feet.

THE NATIONAL OBSERVATORY OF BRAZIL (3500 FEET).

The observatory of Rio de Janeiro is to be removed to Petropolis (3500 feet), but I have not been able to find any reports on the astronomical conditions which prevail there.

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* Potosi (4100 metres) formerly contained 100,000 inhabitants.

CHAPTER III.—THE OBSERVATORIES OF NORTH AMERICA.

METEOROLOGICAL STATION AT MOUNT WASHINGTON (6279 FEET).

This station was occupied as a signal station by the United States Government for seventeen years, and was closed in 1888.

The mean temperature at Mt. Washington is about 26° F., the highest observed was 74°, the lowest, – 50°, the average daily range being about 14°.

"Mount Washington not only has higher winds than the summit of Pike's Peak for short periods, but also for days and months. On February 27, 1886, the mean hourly velocity at Mt. Washington was 111 miles for the entire day, and in January, 1878, the extraordinary velocity of 186 miles per hour was recorded." The wind at the summit has about five and one half times the velocity at sea level. The mean annual cloudiness at this station is 57 per centum, and the cloudiness, together with the high winds, makes the summit quite unfit for ordinary astronomical observations.

For completeness I may add that a railway to the summit has been available since 1869.

ASTRONOMICAL OBSERVATIONS AT SUMMIT IN THE SIERRA NEVADA (7200 FEET). BY PROFESSOR G. DAVIDSON.

Professor Davidson's report to the Chief of the Coast Survey begins thus: "In accordance with a plan I submitted to you on the 16th of February (1872) I occupied a station . . . at Summit . . . to determine whether great elevations were better than small ones for astronomical observations." The station was occupied during July and part of August, 1872. Meteorological records for 358 consecutive days (December, 1866, to December, 1867) show 270 of them to have been clear. The total snowfall was 45 feet.

The astronomical observations and tests at Summit were made with two telescopes. With the first (aperture, 2 inches; magnifying power, 35 to 40) the companion to *Polaris* was seen. This, however, is not remarkable. It has been seen in New York City by Dr. Henry

FIGURE 17:—DISTANT VIEW OF PIKE'S PEAK, (14,134 feet).

Draper with an excellent telescope owned by him, of $1\frac{1}{4}$-inch aperture and power of 60. The second telescope employed at Summit was of 3-inch aperture with powers of 60 or 65 and 250. The tests were made on *Polaris*, *Saturn*, the moon, the sun, and a few double stars. The results were very favorable for steadiness of the images; and it is noteworthy that the solar image was extremely sharp and steady. The excessive snowfall would unfit this station for permanent occupation. The same remark applies to the station first selected for the Lick Observatory at Lake Tahoe.

U. S. Coast and Geodetic Survey Station, Sherman, Wyoming (8335 feet).

In 1872 the U. S. Congress appropriated the sum of $2,000 to enable the Superintendent of the Coast Survey to make "astronomical observations at one of the highest points on the line of the Pacific railroad." During the summer of 1872 a station was occupied by a party under Mr. R. D. Cutts, of the Survey, and astronomical and meteorological observations were made.

Mr. Cutts reports the sky as "indescribably brilliant," and the stars as very steady.

Professor C. A. Young was invited by the Coast Survey to occupy this station, and spent the months of June, July, and August, 1872, at Sherman, engaged in astronomical observations, chiefly spectroscopic. He brought with him a 9.4-inch equatorial by Clark, with its spectroscope. The number of good days was small—about one in three. "But when the sky was clear, it was beautifully so." Many 7th magnitude stars were visible to the naked eye. *Alpha Lyræ* was several times observed with the naked eye from 10 to 15 minutes before sunset. Most of Professor Young's work was done in the daytime on the sun, but on 7 nights from 3 to 4 hours were spent in the observatory. On two of the nights the seeing was perfect; on two others, fine; on three it ranged from fair to poor. Finally, Professor Young states it as his deliberate opinion that a 9.4-inch object-glass at Sherman is just about equal to a 12-inch at sea-level.

It is important to remark that this expedition of Professor Young's was the first one in which a telescope of considerable power was continuously used at a high elevation. His results, and specially his spectroscopic results, soon became widely known, not only in scientific circles but throughout the world. The establishment of the Lick Observatory on a mountain was partly due to his success, and the Lick Observatory is the forerunner, and in some sense the parent, of the mountain astronomical observatories of to-day.

Sherman was by no means an ideal station, but the observations of Professor Young, and especially the spectroscopic observations of the sun, showed the immense advantages of a high-level station far above the dust and mists of the lower atmosphere, when the condition of steadiness was added to that of transparency.

It is not necessary to give an account of these spectroscopic observations which are well known to all interested,* but it may be mentioned that at Dartmouth College Professor Young had been able to map 103 spectral lines which are reversed in the chromosphere. In six weeks at Sherman all these were verified and 170 new ones added. This is a striking proof of the excellence of the atmospheric conditions and of the assiduity of the observer.

Rocky Mountain Stations in Central Colorado.

During the summer of 1873 I spent several weeks in Colorado, always at altitudes above 5000 feet, and frequently at 9000 and 10,000—and occasionally at heights of 13,000 feet and even more. The region around Pike's Peak, on its flanks, and throughout the South Park, was pretty thoroughly traversed—at Manitou, Florissant Valley, Central City, Idaho Springs, Fairplay, Mount Bross (near Mt. Lincoln), Cañon City, etc. In July, 1878, this region was again visited and I made a stay of about a week at Central City (8400 feet) and vicinity. A third visit was made in December, 1885. On all these occasions comparisons were made (with the naked eye, opera-glasses, or small telescopes) between the conditions of vision at Washington and those in the Rocky Mountains. Objects with which I was familiar (usually groups of stars, as the region bounded by the four brightest stars of *Ursa major*, of *Lyra*, etc.) were studied and mapped at both stations to determine the relative transparency of the air in the East and in the Rocky Mountain region in question; and careful notes were made of the relative amounts of twinkling of the stars at both stations.

During six journeys across the continent from the east to the Pacific and return in the years 1881, 1883, 1885, 1886 similar experiments were made, whenever possible, both on the Southern Pacific and Union Pacific railways. All these observations taken together simply confirmed the conclusions reached in 1873, which I then reported to the Superintendent of the U. S. Naval Observatory and to astronomers in Washington. These conclusions briefly stated were:

1. The transparency of the air at heights of 6000–14,000 feet in this Rocky Mountain region was always markedly superior to that at eastern stations, as was to be expected.

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* *See* Professor Young's book. *The Sun.*

2. The steadiness of the air, as tested by the absence of scintillation of the stars, was usually *inferior* to the steadiness at Washington.

3. A very few nights at the western stations were not only extremely transparent but very steady; and thus superior to anything to be experienced in the east. But, unfortunately, such nights were very exceptional. The practical conclusion from all this was that there was no reason to believe that the 26-inch telescope of the Naval Observatory would do better service, on the whole, in this region of the Rocky Mountains than at Washington. This conclusion was reported to Dr. Henry Draper in 1874, and was tested by him in his journeys to Wyoming, Utah, and Colorado in 1876, and it was entirely confirmed by his independent observations in various parts of the Rocky Mountain region. It has since been confirmed by parties from the Harvard College Observatory (1887), also, for certain selected stations.

Professor Campbell, now of the Lick Observatory, left the observatory of Ann Arbor to become head of the Department of Mathematics in the University of Colorado, at Boulder (5,500 feet), where he spent several years. His report is that the sky is of great purity, but that the stars are extremely unsteady; thus adding one more bit of expert testimony and again confirming the general verdict as to the conditions to be found in the Rocky Mountains generally.

I have no doubt that the final verdict upon the Rocky Mountain region in Montana, Wyoming, Colorado, and at least part of New Mexico will be that it is not in general desirable to establish permanent astronomical observatories on high mountains in these States. It is possible that special stations *may* be found where special local conditions may change this general conclusion. The States of California, Arizona, and part of New Mexico will, probably, always be preferable to the Rocky Mountain region proper, for mountain, astronomical, observatories.

Rocky Mountain Stations in Utah, Wyoming, and Colorado.

In August and September, 1876, Dr. Henry Draper made a journey in the Rocky Mountains and paid especial attention to the conditions of the atmosphere for astronomical observations. He took with him a small but very perfect achromatic telescope of $1\frac{1}{4}$ inch aperture and magnifying power of 60 diameters. Stations in the Wahsatch Mountains of Utah and in the Rocky Mountains of Wyoming and Colorado, from 4500 to 11,000 feet in elevation, were occupied. Professor Draper's general conclusions were:

> On the whole, the astronomical condition, particularly for photographic researches, is unpromising. In only one place were steadiness and transparency combined, and only two nights out of fifteen were exceptionally fine. The trans-

parency was almost always much more marked than at the sea-level, but the tremulousness was as great as, or even greater than, at New York. It is certain that during more than half the year no work of a delicate character could be done. . . . Apparently, therefore, judging from present information, it would not be judicious to move a large telescope and physical observatory into these mountains with the hope of doing continuous work under the most favorable circumstances.

Professor A. Hall, Sr., observed the eclipse of July, 1878, at La Junta, which lies in the elevated plains of Colorado, about 4187 feet above the sea. "I cannot but think," he says, "that these elevated plains afford advantages for astronomical observations that have not hitherto been made use of"—which was true then, and is largely true to-day.

In July, 1878, Mr. Alvan G. Clark used a high-power eyepiece on a 3-inch telescope at Creston (Wyoming), altitude 7000 feet, and examined some close double-stars for about two hours. His verdict was that *Epsilon Lyræ* was "as well shown as he had ever seen it at Cambridge with a 12-inch glass!!!" The two hours in question was the only good observing weather during the stay of the eclipse party of which he was a member.

Project for the Establishment of a Branch Naval Observatory on the Western Plains (1878).

In the early part of 1878 the Hon. A. S. Paddock, U. S. Senator from Nebraska, addressed a letter to the Secretary of the Navy on the matter of the establishment of a branch of the U. S. Naval Observatory at some elevated station in the interior of the continent. The letter was referred to the Superintendent of the U. S. Naval Observatory, and his endorsement, together with those of Professors Hall, Harkness, Eastman, and Holden, is printed in *Miscellaneous Document*, No. 25, U. S. Senate, 45th Congress, 2d Session.

Admiral John Rodgers is in favor of the project, but points out that a suitable site can only be found by trials, and recommends that an appropriation of $12,000 be made for the purpose of making such trials, and that, when the proper site is found, a branch observatory be located there which shall be devoted chiefly to work of discovery. Admiral Rodgers points out in clear and forcible language that the largest part of the work of a Government observatory is of a routine character, useful if not brilliant; and that such work will always be better done near to the centres of intelligence, "where libraries are found, where opinions are interchanged, and aims are canvassed, where artistic skill is to be met, and supply of material is to be found. The observatory of discovery should be a branch of the observatory of useful work." (I presume that for "useful" one should read "more immediately practical.") Professor Hall reports that for some time he has been collecting evidence on the question and now thinks "that by establishing a large telescope on the lofty plains of the West, we have a simple and an easy means of making a forward step in practical astronomy." The opinions of Professors Harkness, Eastman, and Holden agree with those just cited from general considerations; and the latter is able to refer to some experiments of his own in 1873 on the subject, which support the general conclusion. The proposal of Admiral Rodgers to make a series of actual trials of proposed sites was suggested to him by the programme for the Lick Observatory prepared in 1874 by Professors Newcomb and Holden.

The Lick Observatory on Mount Hamilton (4209 feet).

The observatory on Mt. Hamilton was built under the direction of successive sets of trustees appointed by Mr. Lick, essentially on the plans prepared by Professor Newcomb and myself in 1874.*

An inspection of the many plans and projects submitted to the Lick Trustees during the years 1874 onwards would show more plainly than any other process can how little was then generally known of the conditions which should govern in the selection of a site for a mountain observatory and in the construction of its buildings, etc. The long legal and other delays in the construction of the Lick Observatory (1874–1888) were very costly, but their compensation was obtained in the opportunity for a thorough discussion of all details. The final result has been singularly free from errors of commission; and the omissions have been repaired as far as the available funds have allowed. The principles which governed here were sound, and their successful application has been of much service to many other establishments.

Some of the sites first proposed are now known to be buried in snow for months together; some of the constructions then suggested would be absolutely unworkable here; and some of the astronomical conditions then laid down as essential cannot be realized in any mountainous country. Each point was carefully studied in detail; advice was sought from those most competent to give it; and nothing was decided upon until its effect on future plans was understood. After the searching test of actual use during the years 1883–1896 it may fairly be said that the result is, on the whole, successful, and that the real difficulties have been fairly met and conquered.

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* See *Publications of the Lick Observatory*, vol. I, 1887; and also *Publications of the Astronomical Society of the Pacific*, vol. IV, (1892), page 139.

Professor Burnham's Experiments on Mount Hamilton in 1879 (August 17 to October 17).

In 1874 I suggested to the Lick Trustees that Professor Burnham, using his 6-inch Clark refractor, should test the sites proposed for the Lick Observatory before any final selection was made. In 1875 Mr. Lick selected the summit of Mount Hamilton, after some preliminary tests had been made by Captain Floyd, President of the Lick Trustees, Mr. Frazer, and others, with small telescopes.

Professor Burnham's expedition of 1879 was very important in its systematic examination of double-stars and in its comparison with the conditions obtaining at Chicago. During the whole period of sixty days Professor Burnham reports: First-class nights 42; medium 7; cloudy and foggy 11. His general conclusions may be quoted here, although they are well known, because they have been confirmed by our long experience. They are, in brief, that "there can be no doubt that Mount Hamilton offers advantages superior to those found at any point where a permanent observatory has been established [up to 1879]. The remarkable steadiness of the air, and the continued succession of nights of almost perfect definition are conditions . . . not to be met with elsewhere."

In 1881 Professor Burnham and myself made a stay at Mount Hamilton, after a season of observation at Madison, Wisconsin, which had not changed the opinion above quoted. It is interesting to remark that the site chosen for the 40-inch Yerkes refractor of the University of Chicago lies about midway between Chicago and Madison. Unless the conditions at Lake Geneva, Wisconsin, are distinctly better than those of the region near by, its selection as a site for the largest of telescopes may turn out to have been an error of judgment.

Dryness of the atmosphere: Meteorological observations taken at Mount Hamilton during the years 1888 to 1896 will soon be printed in a special volume of the *Contributions from the Lick Observatory*. An inspection of such tables in detail will exhibit, better than any words, the remarkable conditions which exist here during the most favorable observing weather, May to November.

A botanical survey of the mountain was made, at my request, by Professor Greene of the University of California in 1893, and a sentence from his report* exhibits the integral, as it were, of many separate conditions:

. . . Mount Hamilton having been chosen as the site of the Lick Observatory on account of its being a fair-weather mountain . . . it must be interest-

* *Erythea*, vol. I, No. 4, April, 1893, page 77.

ing to note how well the native vegetation . . . would have indicated to the botanist the relative immunity of this mountain-top from fogs and long-continued rains.

Professor Greene finds that the species of trees, etc., on Mount Hamilton are nearly always those of the dry interior of the State rather than those of the coast ranges, and that the botanical region has its affinities with the dry San Bernardino mountains rather than with the peaks of the coast range lying very much nearer to it.

Purity of the atmosphere at Mt. Hamilton: North winds, in summer, bring dust from the Sacramento valley to surround us, and forest-fires near us, or even those of Oregon, sometimes fill the whole atmosphere with haze. When neither of these hindrances is obvious, that is for a very large proportion of the days, the air is of great purity. Two obvious proofs of it may be cited. The sky-glare near the sun is weak; and the atmospheric spectrum at sunset is beautifully clear and finely graded. Nearly all our summer sunsets are cloudless. The sky is a deep orange near the horizon and shades off through the prismatic colors, in a vertical circle, to the pure upper blue. No one who has seen this effect once will forget it, and to mention it will recall it to all who have lived with us. The photographs of sunsets at Mount Hamilton made by Mr. Colton * show the sun sinking into banks of dust or fog, not into clouds (consult the accompanying table of zenith-distances)

Daytime observations: All our experience at Mount Hamilton goes to show that the steadiness of vision in the daytime is certainly no better than that of American observatories generally, and that it is, probably, somewhat less good, though the difference is not very striking. The reason is twofold. In the first place the topographical situation of the observatory, surrounded as it is on all sides by steep slopes, exposes the instruments to whatever ascending currents of air there may be far more than if the observatory plateau were larger. This is a cause which can never be removed.

In the second place the slopes which immediately surround the plateau are composed of fragments of bare rock, which become intensely heated during the day, and whose radiations seriously affect the seeing. This cause can be done away with by planting trees and sowing grass and vines over the rock slopes. Experiments in this direction were urged on the Lick Trustees in 1881 and subsequently; and were begun in 1888. A considerable amount of water is needed in our excessively dry, and long, summers to prevent ordinary grasses from dying by drought, and there has been no adequate quantity of water available for this purpose. The (rain-water) reservoir capacity was considerably increased during the summer of 1895, and some water

* *Contributions from the Lick Observatory*, No. 5.

can now be spared for such experiments. Even if they are only partially successful the conditions of daylight vision will be improved.

Observations which can be made at almost any hour of the day (as spectroscopic and photographic observations of the sun) can usually, by diligence, be well made here, by choosing the best moments. The long series of solar photographs (many being excellent) obtained here by Mr. Perrine prove that such moments can be selected.

The negatives of the Transit of *Venus* of 1882 which were secured at Mt. Hamilton (by Professor Todd) are said to be the best of any which were measured at Washington.

Observations which must be made at a fixed instant (as meridian-transits of sun and stars) are, on the whole, not likely to be observed under as good conditions here as at the average observatory in the east. As the slopes of the plateau become covered with vegetation these difficulties will be in part removed, but in part only.

The effect of fog in the valleys on good vision: During my visits to Mount Hamilton in the years 1881 and subsequently I made careful notes of the conditions of good vision at the summit. The phenomena of an average summer day occur somewhat as follows: The sun rises in a clear sky, and no clouds are visible during the entire twenty-four hours. The days are hot (though, of course, not oppressive, since the air is exceedingly dry), and the vision during the day is usually unsteady on account of air-currents which rise from the neighboring cañons and from the heated rocks immediately bordering the plateau of the summit. The large valley of Santa Clara lies all day long in the ardent sunshine. Late in the afternoon the sea fog begins to creep in through the various gaps in the coast-range (which borders the Santa Clara valley on the west) and to come towards the north from Monterey Bay through the valley of the Pajaro River, etc. A local fog from the Bay of San Francisco often sends its thinner veils towards the south, but seldom extends as far south as Gilroy, where the Monterey fog is entering. Up to this time the fogs are low-lying. As the afternoon goes on the sea-fog rises higher and higher, and often pours over the tops of the highest peaks of the Coast-Range (3000 to 3800 feet), and completely covers the valley of Santa Clara, and fills our neighboring cañons close below us, but seldom (in summer) rises to our own level. Usually it is say 1000 feet lower. The hotel at the foot of the mountain has *frequent* fogs in summer (it is 2000 feet lower) when Mt. Hamilton has none.

The night fogs (in summer) seldom rise to the summit, and they are dissipated in the early morning.

As the autumn comes on the fogs rise higher and higher, and finally a day comes when the summit is covered. This is the precursor of a change of season. This day may be followed by weeks of good weather, with only an occasional foggy afternoon and night.

Such is a very succinct account of the *average* summer day. There are exceptional days of fog at the summit, of no fog in the valley, and days when the trade-winds (which bring fog) are replaced by northers; but, in general, the above account represents the typical summer day. During all the summer the vision is, as a rule, steady, and for very many days it is remarkably so. If 3 represents the average seeing of the year (on a scale of 1 = very poor, to 5 = perfect steadiness) the days of June and early July are apt, in the long run, to be of grade 4, while late July, August, and part of September are of even higher excellence, and contain a considerable number of nights of perfect, or nearly perfect, seeing. In this brief account allowance must be made for exceptions, but, in the large, the course is about as just recited. If the seeing is good for part of a night it is usually good throughout.

In seeking for a cause of the excellent conditions of vision which prevail here during the summer nights, it appeared to me to be largely due to the banks of fog which lie over the Santa Clara valley. During the day that valley and our surrounding foot-hills, etc., are intensely heated. The thick layer of fog which often covers them from sunset onwards acts as a screen to shut in the radiations, and to allow the higher summits (as Mt. Hamilton) to quickly cool, and to take the temperature of the superincumbent air.

There is no doubt whatever that our best nights usually follow days when the fog has covered the valleys (though there are exceptions). The very best vision is usually accompanied by calms or very light airs. There is no doubt whatever that when we can see the electric lights of San José some thirteen miles away and 4000 feet below us (and thus when there is no fog) the nights are usually not of first-class excellence (though there are exceptions).*

During the years 1881–88 my stays at Mt. Hamilton were seldom so long as a month. The exceptional cases did not then impress me, and I was disposed to attribute the excellence of our summer vision almost entirely to the presence of the low-lying sea fogs. I still think that they are the principal factor; but an experience of actual residence during the years 1888–1896 has proved to us all that the explanation

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* When the lights of San José can be seen they are usually very unsteady, as might be expected, and the vision at Mount Hamilton is usually not good, as I have said. There are, however, occasions when the San José lights appear quite steady and yet are clearly seen; and on such occasions the vision at Mount Hamilton is usually good, though seldom perfect. The latter conditions are usually accompanied by a calm.

is not so simple, and that other conditions—perhaps many other—enter as efficient factors. Some of these factors are elsewhere considered.

The effect of wind on good vision at Mt. Hamilton: In comparatively level regions (as at Caroline Island in the midst of the ocean, at Washington, and at Madison), my experience has been that winds, even high winds, did not affect the seeing unfavorably. The general horizontality of air-strata of equal temperature is not affected under such circumstances, and local pockets of hot or cold air are broken up.

In his *Report* of 1879 Professor Burnham concludes that high winds at Mt. Hamilton do not affect the seeing unfavorably. My own experience does not agree with this conclusion. High winds at Mt. Hamilton (owing to the topography) produce currents of very varying directions, and prevent a stable arrangement of the air-strata, and the effect on the vision is, in my experience, often quite marked, and this without any exception that I can recall.

Vision at Mt. Hamilton during the presence of auroras: Professor Campbell has shown that the auroral line is pretty constantly present in the sky-spectrum, though auroras are seldom visible (here) to the eye.

Whenever they are so visible, the images of stars are invariably bad. This connection was even more obvious at the Washburn Observatory. It was easy to predict from a peculiar appearance of stars in the 15½-inch equatorial that my assistant would see an aurora from the north window of the dome, and the predictions were made and tested on scores of occasions. At Mt. Hamilton visible auroras, intense neuralgic headaches, and poor stellar images seem to depend on one and the same cause.

Winter observing weather at Mt. Hamilton: The conditions during Mt. Hamilton winters are so markedly inferior to those which prevail during the summer, that the observers here are apt to underrate them. In a general way I think it is true that the winters at Mt. Hamilton afford as many clear days and as many days of good steady vision as those of Madison, Ann Arbor, or Cambridge. One winter may differ greatly from another in this respect, but on the average the foregoing statement (which is based on impressions and not on statistics) will probably hold good.

Comparison of different years at Mt. Hamilton: A glance at the complete meteorological statistics of Mt. Hamilton (elsewhere printed), will exhibit the great difference between different years taken as a whole. The summers are apt to be much alike, though they, also, vary. The winters vary in an extraordinary fashion. The total snow-fall of the winter of 1889–90 was about 12 feet; that of 1890–91 about 14¼ inches. The average *yearly* rainfall is 33.18 inches.

The rainfall for the month of December, 1884, was 33.8 inches! The following summary of rainfall and temperature observations will be found interesting and instructive:

SUMMARY OF RAINFALL AND TEMPERATURE OBSERVATIONS FROM SEPTEMBER, 1880, TO NOVEMBER, 1893, INCLUSIVE, AT THE LICK OBSERVATORY [COMPILED BY C. D. PERRINE]. *

MONTH.	Average Rainfall.	TEMPERATURE (Fahr.).					
		Average Maximum.	Average Minimum.	Mean.	Highest Maximum on Record.	Lowest Minimum on Record	Average Daily Range.
	inches	°	°	°	°	°	°
July	0.00	79.2	60.6	69.9	94	36	18.6
August	0.01	80.0	63.3	71.7	96	39	16.7
September	0.30	73.5	56.1	64.8	93	30	17.4
October	1.44	62.9	46.9	54.9	88	25	16.0
November	2.56	56.2	41.5	48.9	88	26	14.7
December	9.06	49.7	36.3	43.0	72	17	13.4
January	3.85	48.4	36.6	42.5	72	14	11.8
February	4.31	47.9	33.6	40.7	74	12	14.3
March	5.62	51.0	37.0	44.0	80	18	14.0
April	3.68	58.5	37.1	47.8	82	21	21.4
May	1.76	64.0	46.9	55.5	90	28	17.1
June	0.59	70.0	51.1	60.5	92	31	18.9
Annual	33.18	61.8	45.6	53.7	....	......	16.2

The following short table exhibits the facts as to the humidity of the air at Mount Hamilton. During the favorable months for observing, the air is usually extremely dry:

RELATIVE HUMIDITY AT 9 P.M. (100 = COMPLETE SATURATION).

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1893	52	80	86	76	61	49	46	55	84	86	66	65
1894	78	78	76	55	74	72	37	33	52	59	47	90
1895	82	58	75	65	59	35	44	55	51	55	58	65

The best possible tests of the condition of the atmosphere are to be had from actual astronomical observations. It may be of interest to recall a few made at Mount Hamilton during the years 1888–1896 which exhibit either the transparency or the steadiness of the atmosphere.

Separation and measurement of close double-stars: The long series of

* *Publications of the Astronomical Society of the Pacific*, vol. VI, p. 47.

observations of Professor Burnham * should be referred to in this connection.

Detection of very faint stars: The observations of Professor Schaeberle and myself on the stars in the *Lyra* nebula,† and of Professor Barnard on the stars of the trapezium of Orion ‡ show stars of the last degree of faintness.

Observations of the structure of nebulæ: Reference should be made to papers by Schaeberle and myself § on the *Lyra* and *Draco* nebulæ.

Observations of faint satellites: The faint satellites of *Mars* are observed here as easy objects. They have been seen when their brightness was but 0.12 of that at the time of their discovery in 1877.‖ The fifth satellite of *Jupiter* was discovered here by Professor Barnard.¶

Observations of the Zodiacal Light: Professor Barnard's observations of the zodiacal light are noteworthy.**

Observations of comets: The observations of the faint companions of Brook's comet (1889, V) by Professor Barnard are especially instructive. They were discovered with the 36-inch equatorial and two of them (D and E) were seen, I believe, at no other observatory. The 12-inch refractor here was never able to show the fainter companion comets †† which is a fact of importance.

Definition of the surface features of the planets Mars, Jupiter, and Saturn: A long series of drawings of these planets by Messrs Schaeberle, Keeler, Barnard, Campbell, Hussey, and myself ‡‡ shows details of surface features in a very satisfactory manner. The bright projections at the terminator were first discovered and measured with the 36-inch telescope §§ and the fine division of the outer ring of *Saturn*, discovered by Professor Keeler in 1888, was not detected elsewhere.‖‖

Nothing could be more satisfactory than the observations of the phases of the eclipses of *Jupiter's* satellites, first regularly observed here. ¶¶

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* *Publications of the Lick Observatory*, vol. II.

† *Monthly Notices*, R. A. S., vol. XLVIII, p. 383.

‡ *Publications of the Lick Observatory*, vol. II, p. 48.

§ *Monthly Notices*, R. A. S., vol. XLVIII, pp. 385, 388.

‖ *Astronomical Journal*, No. 178.

¶ *Ibid.*, No. 275.

** *Ibid.*, No. 243.

†† *Astronomische Nachrichten*, No. 2919, and *Publications of the Astronomical Society of the Pacific*, vol. II, (1890), p. 26.

‡‡ *Publications of the Astronomical Society of the Pacific*, various vols.

§§ *Ibid.*, vol. II, p. 248 ; vol. VI, p. 103; vol. VI, p. 285.

‖‖ *Astronomical Journal*, No. 192.

¶¶ *Publications of the Astronomical Society of the Pacific*, vol. III, p. 263.

FIGURE 18:—MT. WHITNEY (14,900 feet), FROM THE WEST.

Markings on the discs of *Jupiter's* satellites have been systematically studied.*

Precise determination of star-places: Mr. Tucker's observations of star-positions (not yet published) extend over 2½ years, and comprise about 5000 determinations of some 300 stars. The probable error of a single R. A. is $0^s.020$; of a single Decl. $0''.25$.

Photography of the Moon, Milky-Way, and Comets: The photography of the Moon,† Milky-Way, ‡ and of Comets, § and photographic-photometric ‖ experiments have been very successfully carried on here, under highly favorable conditions.

Photography of the Sun: More than 1700 negatives of the sun have been made at Mt. Hamilton by Mr. Perrine with the 40-foot photoheliograph. The best of them are extremely good, showing fine detail in the spots and of the faculæ, and permitting a subsequent enlargement of some 6 diameters. The average negative shows considerable detail. There is no doubt, however, that much of the excellence of this long series arises from the care with which the best moments for observation have been chosen, and that the average negative exhibits something better than the average seeing.

Spectroscopic observations: Good definition of star-images and great transparency of the air are powerful aids to spectroscopic observations, both visual and photographic.

Professor Campbell's spectroscopic observations have resulted in a catalogue of 37 lines in the spectra of different nebulæ. ¶

Likewise, the Lick Observatory observations of comet-spectra record 32 bright lines.**

The new star of 1892 (*Nova Aurigæ*) showed 32 lines in its visual, and about 50 lines in its photographic, spectrum to Professor Campbell, against a materially less number elsewhere catalogued. ††

Nineteen lines were registered in the spectrum of *Nova Aurigæ* in August to November, 1892, after the change in the spectrum.‡‡

The nebulous character of *Nova Normæ* was determined §§ when its altitude was less than 2½°; and both bright and dark hydrogen lines

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* *Publications of the Astronomical Society of the Pacific*, vol. III, p. 359.

† *Publications of the Lick Observatory*, vol. III.

‡ *Astrophysical Journal*, vol. II, p. 58, and elsewhere.

§ *Knowledge*, 1891, p. 229; *Astronomy and Astrophysics*, 1893, p. 937; *Publications of the Astronomical Society of the Pacific*, vol. VII, p. 161.

‖ *Contributions from the Lick Observatory*, No. 3.

¶ *Astronomy and Astrophysics* for May and June, 1894.

** *Publications of the Astronomical Society of the Pacific*, No. 31.

†† *Ibid.*, No. 26.

‡‡ *Ibid.*

§§ *Astronomy and Astrophysics* for April, 1894.

were found in the spectrum of γ *Argus* when its altitude was less than 6°.*

The probable-error of a single observation of the velocity in the line of sight of a star like *Arcturus*, for example, is certainly not above 0.35 mile per second. The probable-error of the determination of the wave-length of the chief nebular line is 0.03 tenth-metre.†

Motion of Nebulæ in the line of sight: The determination of the motion of nebulæ in the line of sight was first made at Mount Hamilton by Dr. Keeler.‡

The preceding summary of results actually attained is the best possible testimony to the suitability of the astronomical conditions which prevail at Mt. Hamilton. Almost all departments of practical astronomy are represented by long series of observations, and in nearly every department the actual achievement is satisfying.

During the year 1888 I requested Professor Barnard to keep a record of the *steadiness* (only) of the vision at Mt. Hamilton on a scale of 1 = images extremely unsteady, 3 = average steadiness, 5 = images perfectly steady, and this record will subsequently be published by him.

Dr. Langley's Expedition to Mount Whitney (14,900 feet).

The expedition of Dr. Langley to the summit of Mount Whitney in the summer of 1881, presents an excellent example of the advantages which mountain-stations sometimes afford for the prosecution of special researches in astronomy or astronomical physics. §

The particular object of Dr. Langley's expedition was to determine the *solar constant*, that is to evaluate the quantity of radiant heat received from the sun by the outer layer of the earth's atmosphere in a unit of time (as the quantity falling on each square centimetre per minute).

This determination involves an investigation of the selective absorption of the earth's atmosphere at two stations near to each other but differing greatly in altitude. And it is further indispensable that the sky should be clear and dry at both stations.

Mount Whitney in Southern California fulfilled all the required conditions admirably.

Its summit is 14,900 feet in altitude, so that about one-third of the earth's atmosphere lies beneath its level. The mountain is very abrupt, so that the lower station, at Lone Pine (about 3700 feet),

* *Astronomy and Astrophysics* for June, 1894.

† *Publications of the Lick Observatory*, vol. III.

‡ *Ibid.*

§ Dr. Janssen's observations to detect the presence of oxygen in the sun, made at Chamounix and on Mont-Blanc, are a case in point.

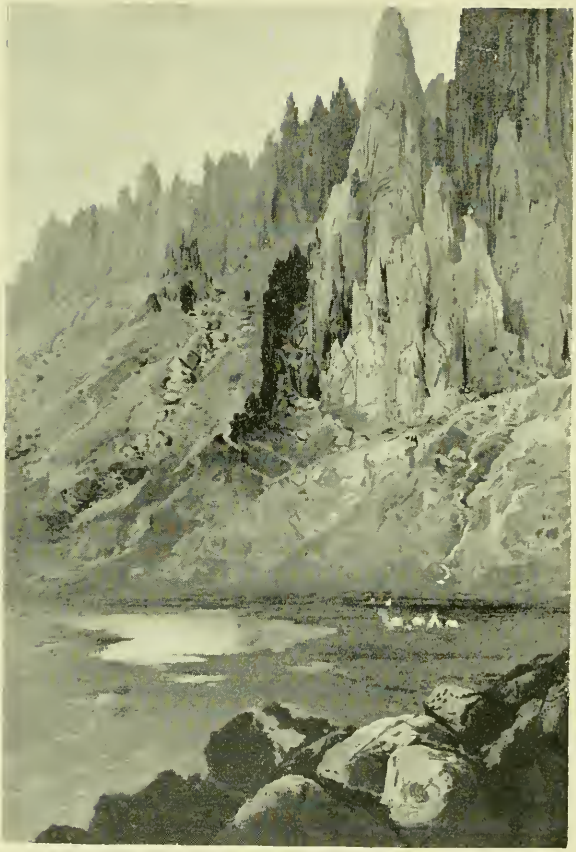

FIGURE 19:—MOUNTAIN CAMP, MT. WHITNEY CALIFORNIA, (12,000 feet).

was close to the upper one, and in full view from it. Much of the work was done at a third station, "Mountain-camp" (12,000 feet). No point east of the Sierras possesses equal advantages for the particular (solar) work referred to. The high peaks in the Rocky Mountains, while admirable as meteorological stations, and comparatively very accessible (Gray's Peak, Pike's Peak, Mt. Lincoln, and many others), are much affected by mist and cloud. Many stations in the Sierras and in other ranges in California and neighboring States are entirely suitable, but as Mount Whitney was the highest and most southerly of the great peaks it was chosen.

On the recommendation of Dr. Langley, seconded by a Committee of the National Academy of Sciences, the Congress of the United States has reserved from sale a considerable area, including the summit and surroundings of Mt. Whitney, so that this station will be forever available for the study of physical problems. A railway passes near the foot of the mountain, and a comparatively small expenditure would open practicable trails for baggage animals to the Mountain-Camp above mentioned. During summer there is comparatively little snow even at the highest part of the mountain mass.

Mt. Whitney has, thus, many advantages as a high-level station for meteorological and special astrophysical researches. It should be borne in mind that its summit is but 880 feet lower than Mt. Blanc; and especially that it is very easy of ascent as far as 12,000 feet. The summit itself, some 3000 feet higher, can be reached in about three hours from the mountain-camp.

From Dr. Langley's notes I extract a few sentences bearing on the astronomical conditions on Mt. Whitney:

August 16. The sky to-day, as always, is of the most deep violet-blue, such as we never, under any circumstances, see at the sea-level. It is absolutely cloudless, and there is only a slight orange tint about the horizon at sunset. Carrying a screen in the hand between the eye and the sun, till the eye is shaded from the direct rays, it can follow this blue up to the edge of the solar disc without finding any loss of this deep violet or any milkiness of the sky as we approach the limb. It is an incomparably beautiful sky for the observer's purposes, such as I have not seen equalled in the Rocky Mountains, in Egypt, or on Mt. Etna.

It is perfectly safe to add to Dr. Langley's enthusiastic testimony that there are literally hundreds of stations in California and the neighboring States of equal altitude with his mountain-camp (12,000 feet) where equally satisfactory observing conditions prevail, so far as transparency is concerned.

Dr. Langley's remarks above relate principally to the *clearness* of the sky. Its *steadiness*, as judged by the absence of twinkling of the stars, etc., was not thoroughly tested. Such tests as could be made are, however, spoken of as satisfactory.

Further tests of the clearness, the transparency, of the air proved to Dr. Langley's that the atmosphere above 12,000 feet still contained a considerable amount of dust. This dust-shell exists all over the world, in Europe, Asia, and America, and it extends considerably above 12,000 feet, though by far the greater portion of it is within 2000 or 3000 feet of the earth.

The smoke from forest-fires in the neighborhood also did its part. In spite of these drawbacks the sky at the summit and at the mountain-camp always showed itself very much more transparent than at the various stations in the Rocky Mountains or in Europe which Dr. Langley had previously occupied. Even the station at Lone Pine had a sky much purer than that seen at the Allegheny Observatory, except on rare occasions.

During the dry season in California the weather is likely to be fair for months at a time (May to October).

After an experience of some two months on the mountain, Dr. Langley sums up as follows:

I hope I have made plain my own belief that Mount Whitney is an excellent station for the purpose for which it was chosen. The great drawback in our case was the inability to remain permanently at the very summit, for to do this requires a permanent shelter. But a railroad will shortly run through Inyo Valley,* and from this, by the aid of an easily constructed mule-path, the ascent of the very highest peak can be made in a day, while the telegraph will put it in direct communication with Washington. I do not think the Italian Government in its observatory on Etna, the French in that of the Puy de Dome, or any other nation, at any other occupied station, has a finer site for such a purpose than the United States possess in Whitney and its neighboring peaks, and it is most earnestly to be hoped that something more than a mere ordinary meteorological station will be finally erected here, and that the almost unequalled advantages of this site will be developed by the Government.

Stations in Colorado Occupied by the Harvard College Observatory.

In 1887 the Harvard College Observatory became possessed of the Boyden Fund, left by Mr. Boyden to aid in the establishment of an observatory "at such an elevation as to be free, as far as practicable, from impediments . . . due to atmospheric influences." In 1887 the Harvard College Observatory sent an expedition to occupy various stations in Colorado. A 12-inch equatorial was set up at three stations —namely, Colorado Springs (6035 feet), Seven Lakes (10,964 feet),

*It is now in operation.—E. S. H.

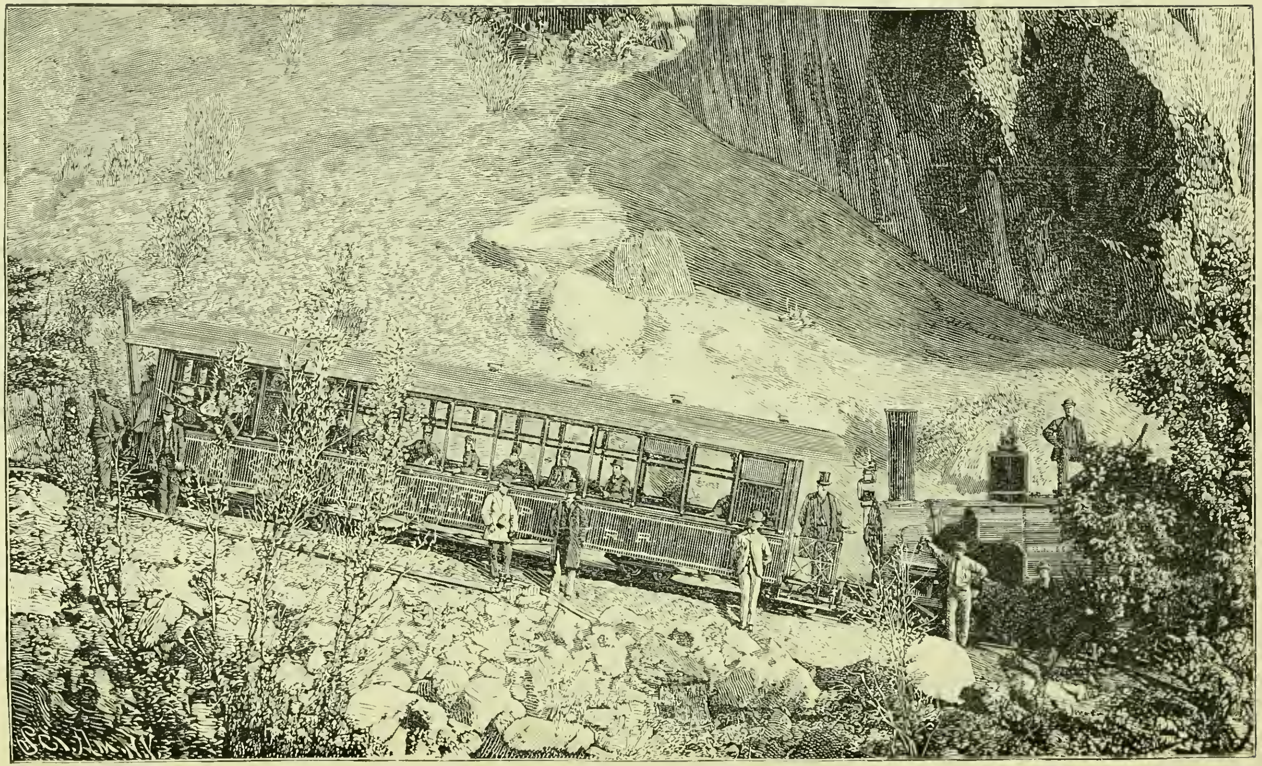

FIGURE 20:—VIEW OF THE RAILWAY TO THE SUMMIT OF PIKE'S PEAK.

and on the summit of Pike's Peak (14,147 feet). Stations at Mt. Lincoln (14,200 feet) and vicinity were also examined.

Professor William Pickering reports that "with regard to the steadiness of seeing no appreciable advantage over Cambridge was shown at any of the stations. The skies were undoubtedly somewhat clearer."

The Meteorological Observatory on Pike's Peak (14,134 feet).

The *Annals* of the Harvard College Observatory, vol. XXII, 1889, contain very complete series of meteorological observations during fourteen and a half years (1874–1888), compiled by Professor H. A. Hazen. As this was for many years the highest meteorological station in the world (Leh, Ladakh, being 11,503 feet, the Sonnblick 9843 feet), it will be of interest to give a short summary of the different tables.

In the first place it is well to remark that the station was continuously occupied, without accident, for fifteen years, from October, 1873, till September, 1888. A telegraph line from the summit to the town of Colorado Springs, some ten miles distant and 8000 feet lower, was maintained for a considerable portion of this time. It may be added in this place that a railway was completed to the summit in June, 1891, and that it is regularly operated for the benefit of tourists during the summer. The running time from Manitou (6563 feet) to the summit station (14,115 feet) is an hour and a half, and the fare is $5. The distance from Manitou by rail is 8 miles. The maximum speed is 8 miles, the minimum 3 miles per hour. Here we have a station which can be constantly occupied, is very accessible, and only 1646 feet lower than Mont Blanc. Mountain-sickness does not affect observers permanently stationed there.

The mean temperature of Pike's Peak is about 19° F. The highest observed temperature was 64° and the lowest—39°. The daily range of temperature is never large, the maximum being about 14°.

The average velocity of the wind is high, but by no means excessive; the average hourly velocity being about 27 miles for January, 12 for July.

Severe and prolonged wind-storms are unusual, and the days when the mean hourly velocity equals or exceeds 50 miles are comparatively infrequent. The most remarkable wind-storms on record were those of September 28–29, 1878, when the mean velocity for 24 hours was 71 miles, and December 25, 1883, when the mean velocity was 70 miles per hour. The highest extreme velocity recorded was 112 miles.

The mean annual cloudiness on Pike's Peak is 40 per centum, ranging from 33 per centum in November to 74 per centum in July.

The electrical storms at the summit are fully described by the observers, and they are terrific. By taking proper precautions they are not dangerous to life, though most appalling. The lightning is nearly continuous for long periods, and the deep rolling thunder is shattering to the strongest nerves.

I myself witnessed one of these storms in 1873 from a safe shelter at the foot of the mountain, and I shall never forget it. Columns of lightning seemed to *stand* in place for minutes, and the rolling of the thunder was awful to hear. No amount of reason could prevent the instinctive shrinking from the sudden bursts of lightning and the deafening reports and echoes of the thunder. The observers on the mountain summit were much incommoded by these electrical storms, but learned how to arrange their telegraph instruments, etc., so as to avoid all real danger.

Hailstorms on the mountain are frequent and violent. Snow falls in every month of the year, but not in such quantities as to make work specially difficult.

The extraordinary transparency of the atmosphere at the summit has been remarked by all who have had occasion to test it. The following extract from the journal of the observers is a proof of it:

October 9, 1874. The atmosphere was so transparent that with the aid of a telescope the observer could see the low range of hills on the line of New Mexico (about 130 miles), and the southern portion of Wyoming (about 150 miles); could also distinguish houses and streets in Pueblo (distant 50 miles); and had a fine view of Denver (which is over 75 miles away).

Such an atmosphere as this is perfect for certain astrophysical observations. Unfortunately the *steadiness* of the atmosphere leaves very much to be desired, as is testified to by all observers who have spent any time on the summit.

In July, 1878, Dr. Langley observed the total solar eclipse from the summit of Pike's Peak. He reports that the summit is probably not a suitable station for a large telescope, and concludes that "a somewhat lower station sheltered from the vapor-bearing winds would be much better than the peak itself," say at an elevation of from 8000 to 11,000 feet. He remarks upon the great transparency of the air, and on one occasion was struck with the steadiness of definition.

The party of Professor Langley was much affected by mountain-sickness, and it was necessary for one of them, Professor Abbe, to descend to a lower level, as a physician pronounced his life to be in danger if he remained on the summit.

In 1893 Professor G. E. Hale (H.), Mrs. Hale (L.), and Professor Keeler (K.) went to Colorado to attempt to photograph the solar corona from the summit of Pike's Peak (14,134 feet). The journal of

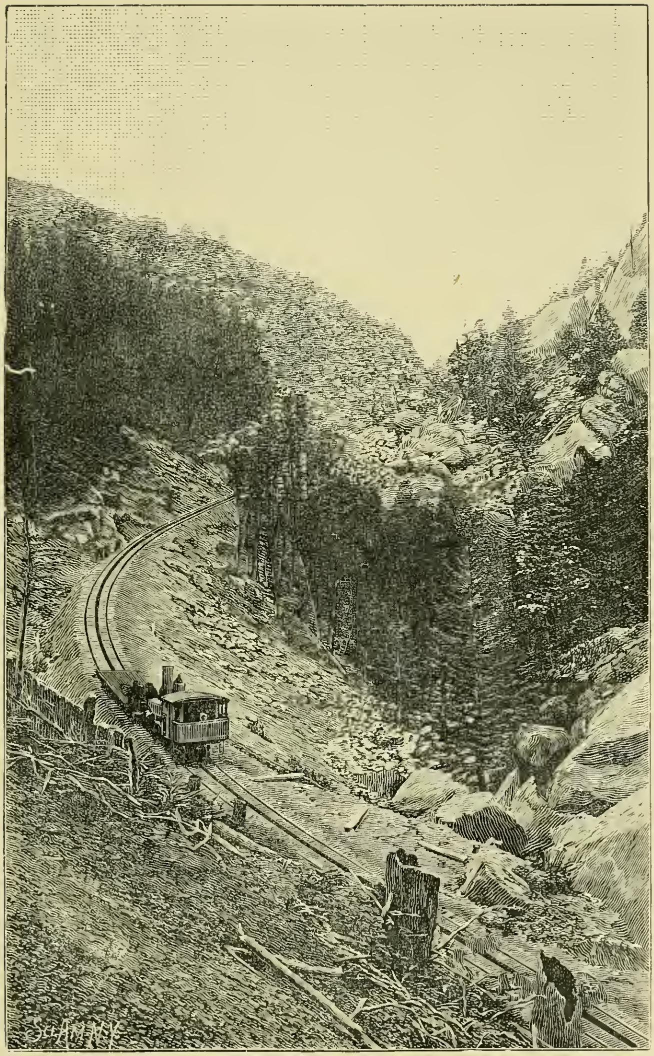

FIGURE 21:—VIEW OF THE RAILWAY TO THE SUMMIT OF PIKE'S PEAK.

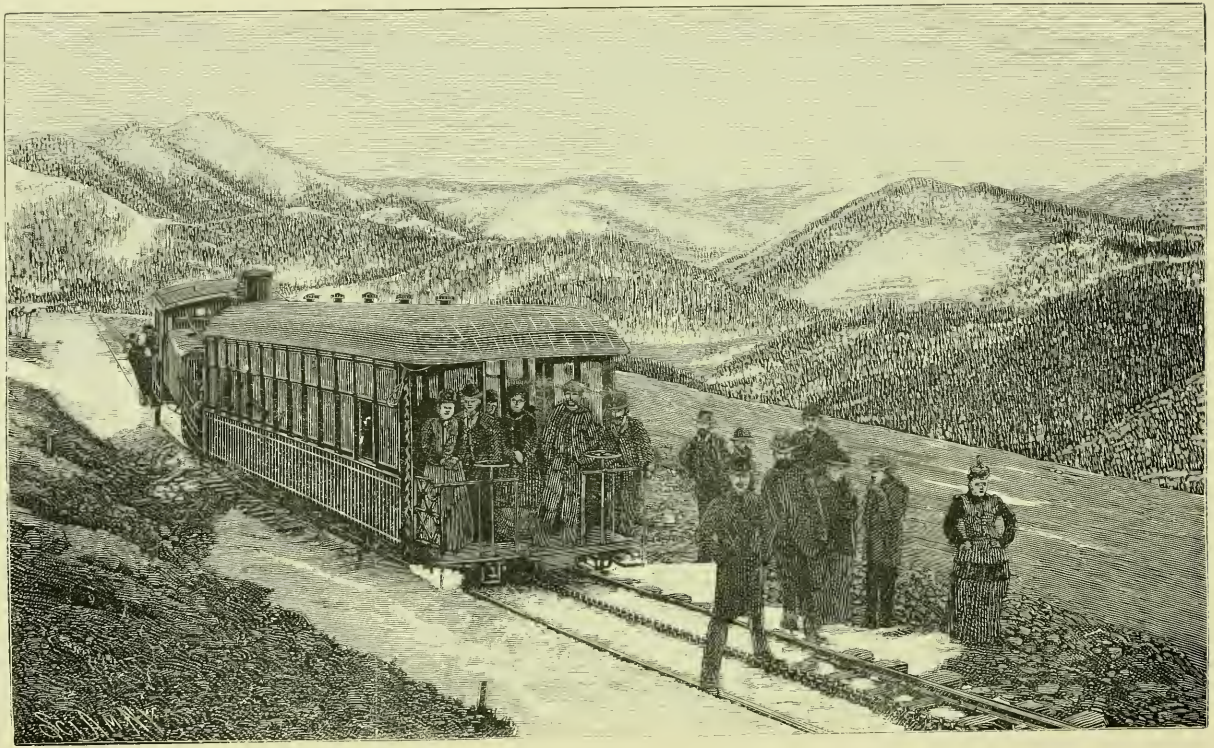

FIGURE 22:—VIEW OF THE RAILWAY TO THE SUMMIT OF PIKE'S PEAK.

their expedition is interesting on many accounts, and it is especially so when compared with a corresponding journal kept at the summit of Mt. Blanc.*

Mr. Hale's diary (in part) is:

1893, June 20: "Went up the peak in the morning train, taking a trunk filled with apparatus and the stand for the telescope. L. and H. returned (P.M.) to Manitou" [*i. e.* to a comfortable hotel].

June 21: "Went up on the morning train." "Suffered considerably from headache due to the altitude."

June 22: "L.'s severe headache continued to grow worse, and it became impossible for her to stay on the peak." "H. and L. went down P.M."

June 23: "H. went up on the morning train."

June 24: "A snow-storm came up, so H. and K. went down on P.M. train," etc.

This going up and down from the summit on trains whenever any obstacle to work occurred presents a lively contrast to the adventures of the party engaged in digging the snow tunnels on Mt. Blanc, with the grim entries: "A tourist and a guide killed by an avalanche" to-day—"Dr. Jacottet died to-day on the summit." When it is remembered that the uses of very high mountain peaks in astronomical observations are *occasional* and not *continuous* (for the solution of special problems, not for consecutive routine observations), the advantage of choosing such a station as Pike's Peak is obvious.

Professor Hale's notes on the weather at the summit should be consulted in his original paper. He found the blueness and purity of the sky interfered with by smoke from forest-fires, and on two occasions by great swarms of insects:

A word as to the suitability of Pike's Peak as a site for astronomical observation. When free from the disturbing effect of forest-fires the sky is of a deep blue at the zenith, and when the conditions are very favorable the blueness persists up to within a short distance of the sun, losing, however, much of its depth of color. During the entire time of our stay the stars appeared to be little or no brighter when seen from the peak than when seen from Manitou, 8000 feet below.†

The scintillation, even near the zenith, was always very marked, and at no time during our stay would the seeing have been even fair. In this respect our experience agrees closely with that of the Harvard College Observatory party which visited the peak some years ago.‡

The altitude of the summit (14,147 feet) § is not greatly inferior to that of

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* *See* an abstract of that journal in the present volume, page 26.

† The naked eye is not sufficiently delicate, nor the memory sufficiently retentive, to make a general observation of this kind very trustworthy. Observations of magnitude regularly conducted would have shown a distinct gain at the higher level, particularly for stars at low altitudes.—Note by E. S. H.

‡ And with my own observations of 1873, 1878, and 1885 made (not on the summit but) at various high stations on the flanks of this mountain and on others in and near the South Park.—Note by E. S. H.

§ 14,134 feet according to *Annals* H. C. O., vol. 22.—Note by E. S. H.

Mont-Blanc (15,780 feet), and the railroad which ascends from Manitou is a great convenience. For such observations as require a blue sky rather than good seeing, Pike's Peak (when not surrounded by forest-fires) would seem to offer some important practical advantages over other mountains of equal altitude. But if good seeing is essential the peak is not to be recommended.

Mountain-Sickness on Pike's Peak.

Professor Hale, 1893, reports that "about two-thirds of the tourists who came up the mountain on the train each morning were affected by the altitude,* and during our stay we saw one or two very serious cases of mountain-sickness. While not much troubled, Professor Keeler and I found prolonged hard work very fatiguing, and any slight extra exertion at once increased the action of the heart."

Mrs. Hale was unable to remain on the summit, although she, naturally, was not called on for any extra exertion there.

Most mountains are (for obvious reasons) quite cloudy (Pike's Peak, Mont-Blanc, etc., as examples). The great advantage of the mountains of California, Arizona, New Mexico, and Southern Colorado is their remarkable freedom from clouds. I have not been able to see any report of the conditions on the mountains of Algeria, but one would think, a priori, that they should be excellent.

Lowell Observatory, Flagstaff, Arizona (7300 feet).

In the *American Meteorological Journal* for March, 1895, Mr. A. E. Douglass, one of the staff of the observatory, gives a table with numerical estimate of the quality of the seeing (its steadiness) from September 28 to December 31, 1894, while he was conducting certain very interesting experiments on air currents within the tubes of large telescopes. These experiments were usually made only when the seeing had become too poor for other observations. The seeing (steadiness) is marked in eleven grades; the best is 10, the worst is 0. It is noteworthy that the seeing was worse than 6 on some part of 48 nights out of 51 nights recorded.†

The conditions at Flagstaff are, then, very different from those at Mount Hamilton (or Mount Wilson) where the whole night is apt to be good if any part of it is so. At Flagstaff it appears that a portion of nearly every night is unsatisfactory, and Mr. Douglass says that almost the entire month of December was so.‡

* The train takes 1 hour 45 minutes to rise from the station at Manitou (6563 feet) to the summit station (14,115 feet). The time required for the journey down is 1 hour 15 minutes. The maximum speed is 8 miles, the minimum, 3 miles per hour.

† I have not counted the estimates for November 2, 3, 4, 5, and 9, where *two* estimates are given, one greater and the other less than 6.

‡ In this connection, see a letter by Professor W. H. Pickering in the section of this volume devoted to the Arequipa Observatory, page 40.

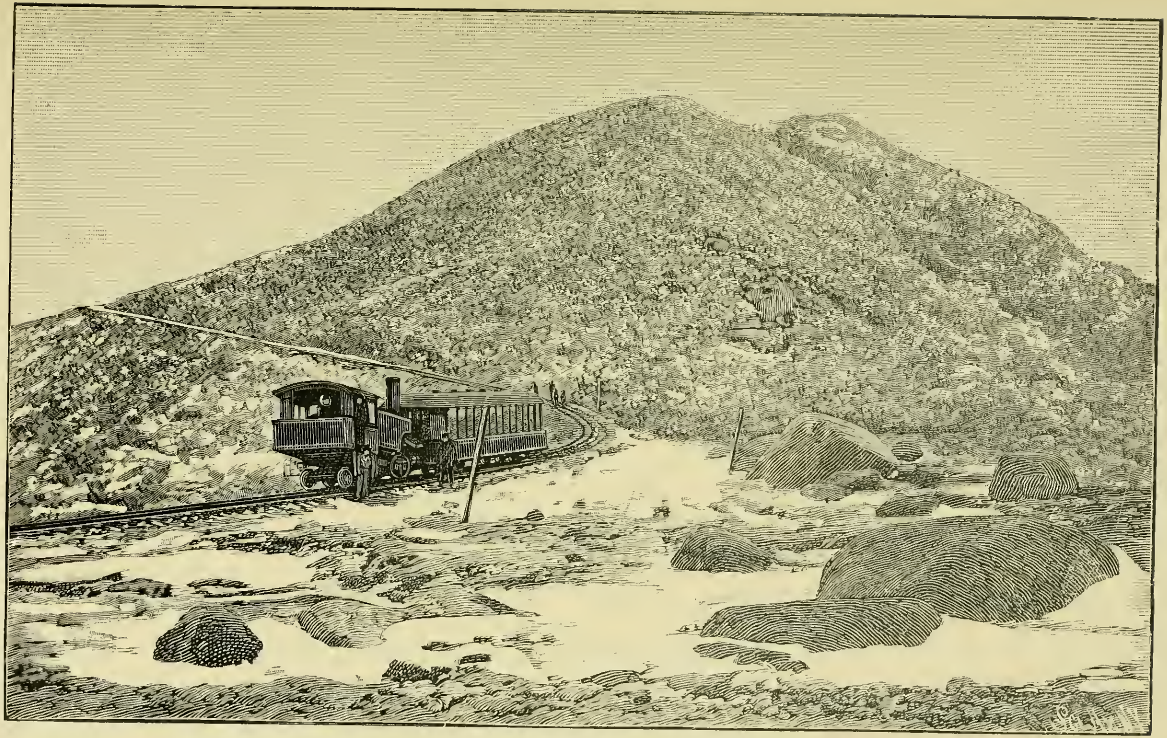

FIGURE 23:—VIEW OF THE RAILWAY TO THE SUMMIT OF PIKE'S PEAK.

FIGURE 24:—VIEW OF THE LOWE OBSERVATORY ON ECHO MOUNTAIN, (3,500 feet).

ECHO MOUNTAIN, CALIFORNIA (3500 FEET).

A private letter from Dr. Lewis Swift gives some statistics of the weather at Echo Mountain which I quote:

Between April 20 and December 1, 1894, there was only one rain of any amount, and during that time the cloudy nights have averaged about three per month. These statistics refer, of course, to the California dry season, the months December to April being much less favorable. But after making all deductions it is obvious that the number of clear nights at Echo Mountain is very much greater than at any observing station east of the Sierra Nevada. Echo Mountain (3500 feet) and Mt. Wilson (4700 feet) are reached by railway from Los Angeles and Pasadena. Mt. Lowe (6000 feet) will soon be accessible in the same way.

CHAMBERLIN OBSERVATORY (5400 FEET) NEAR DENVER, COLORADO.

Professor Howe, Director of the Observatory, in a letter of March 10, 1896, obligingly gives what data are available regarding the newly established observatory. From August 24, 1895, to March 1, 1896—189 nights—must be deducted 65 nights of which no record was kept, chiefly because the moon would interfere with comet-observations. Of the 124 nights remaining 71 were utilized for work:

I consider it safe to say that sixty per cent of the nights were clear. I believe the half-year from September to March is clearer than from March to September.*

My impression of the star-images is that there is more of dancing and shooting out of little arms than at lower altitudes, but less of blurring. On this account faint companions near bright stars are frequently hard to see. . . .

I do not think there are more than twelve or fifteen first-class nights in a year, but this is a matter of estimation rather than actual count.

The transparency of the atmosphere about Denver is well known to be remarkable, and is referred to by Professor Howe.

THE NATIONAL OBSERVATORY OF MEXICO (TACUBAYA) (ABOUT 7500 FEET).

On March 5, 1896, I addressed a letter to Director Anguino asking for data relating to the steadiness of star-images at Tacubaya, based on experience. From his reply of April 9th the following paragraph is quoted:

In respect to the second question, the problem is complicated for us, not only on account of the altitude, but because there is a local cause that perhaps has more influence upon the photographic images—that is, the movement of the dust constantly raised in the valley of Mexico.

As yet we can say nothing that would be well established, since it is a point which I am yet studying, but we can advise you as we advance farther in the study.

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* The clear half-year would be the period of unsteady images, so far as my personal observation in this region holds good.—Note by E. S. H.

So far as I have been able to ascertain from all inquiries, the astronomical conditions near the city of Mexico are not especially favorable. It is reported that Mr. Percival Lowell proposes to establish a 24-inch telescope in this vicinity during 1896. If this is done a good direct comparison with the conditions at Flagstaff, Arizona, can be had, and indirectly a comparison with Mount Lowe, Arequipa, and Mount Hamilton.

In December, 1895, a survey of the volcano Popocatapetl (nearly 18,000 feet in altitude) was made for the purpose of laying out an aërial cable railway to the summit. The object of the railway is to exploit the sulphur beds, but it will, no doubt, lead to the establishment of a high-level meteorological observatory.

CHAPTER IV.—SCIENTIFIC USES OF BALLOONS AND KITES.

Scientific Balloon Ascensions.

The first scientific balloon voyage was made (in London) by Dr. John Jeffries, of Boston, Massachusetts, in the year 1784.* The barometer fell to 21.25 inches (altitude about 9300 feet).

Some of the ascensions and the heights reached are noted below:

		FEET.
Gay-Lussac and Biot, 1804		23,000
Barral and Bixio, 1850	about	23,000
Welsh, 1852	"	23,000
Glaisher, 1862		29,000
Croce-Spinelli, Sivel and Tissandier, 1875 . .	about	29,000
Berson, 1894		30,000

There are three ways in which balloons may be used for scientific observations—(*a*) as captive balloons at comparatively small heights; (*b*) in ascensions carrying observers; and (*c*) as free balloons bearing self-registering instruments, but no observer.

Captive balloons are convenient; but they cannot be sent to great heights, and, in general, it is difficult to keep them at a constant altitude while strong winds are blowing.

Balloons carrying an observer are enabled to obtain the most trustworthy results, but the heights which they command are limited to some 20,000 feet.

Free balloons, carrying only self-registering instruments, have lately been brought to great perfection, and an extreme height of eleven miles has been reached (18,450 *m*).

MM. Gustave Hermite and Besançon succeeded, in 1893, in sending a small balloon to the prodigious height of 52,500 feet (nearly ten miles). The weight of the whole apparatus was about 17 *kilos* (37.5 pounds), and a complete set of self-registering instruments was carried.

* The ascension of the brothers Montgolfier was made in 1782.

The balloon used by M. Hermite was made of goldbeater's skin —an extremely light material. A balloon of this construction, filled with 25,000 cubic feet of hydrogen, will, it is said, keep one man afloat for thirty days. Ordinary balloons have contained 100,000 or more cubic feet of (illuminating) gas, but they are not suitable for prolonged voyages. M. Hermite's balloon held about 4000 cubic feet, but it was filled with coal gas on this occasion. At the start the balloon had a lifting power of 143 pounds.

The balloon started from Paris at 12 h. 25 m. (noon), and after six and three quarter hours landed seventy-eight miles distant. The self-registers recorded automatically every five minutes. At 2.30 P.M. the balloon reached a height of 52,500 feet (nearly ten miles), and the thermometer was at —104° F. A table of the rate of decrease of temperature with increased height has been deduced from the observations, and it is very important. It is not necessary to quote this table here. It shows that the rate of change is more rapid near the earth than in the upper air. The average decrease of temperature was 1° F. per 313 feet.

Dr. Assmann of Berlin has also experimented with small balloons carrying self-registering meteorological instruments, and during the months May–July, 1894, several successful ascensions were made. The readings of the barometer were photographed. On July 7, 1894, the balloon reached an altitude of 53,560 feet, or over ten statute miles.

The greatest height so far reached by such balloons is 18,450 metres, eleven and a half miles. Balloon ascents for scientific purposes are regularly made in Berlin, using large balloons carrying one or two persons. Heights of 10,000–13,000 feet are frequently attained, and the military balloons of the German army are frequently employed in these ascensions. A famous ascent was made in the *Phœnix* balloon by Dr. Berson (December 4, 1894), starting from Strassfurt at 10.28 A.M. At 4200 metres unusual fatigue was felt after exertion ; at 6000 metres slight *malaise ;* at 6750 metres the breathing of pure oxygen gave relief ; above 8000 metres (26,247 feet) oxygen was breathed constantly. Without it dangerous symptoms of dizziness and weakness manifested themselves. The highest point reached was 9150 metres (30,020 feet), at 12.45 P.M. The observer's general condition was good, and his opinion is that he could have gone higher had his store of ballast permitted. The only serious hardship was the extreme cold, — 47°.9 C. = – 54°.2 F. At 3.45 P.M. the balloon was brought to earth near Kiel, thus ending a successful journey—the highest recorded altitude having been reached.

The scientific problems to be solved by such voyages are manifold.

Among those directly affecting astronomical observations are the following:

(1) The rate of the diminution of temperature with altitude and the laws which govern it. The lowest temperature registered by Barral and Bixio (1850) was – 39°.7 C. (= – 39°.5 F.) at 7000 metres (= 22,966 feet). Gross and Berson (1894) found a slightly higher temperature (— 36°. 5 C.) at the altitude of 7700 metres (= 25,262 feet). A balloon carrying self-registering apparatus (but no observer), dispatched by Hermite (1893), recorded – 55° C. (= 58.9 F) at 14,000 metres (45,932 feet); and a similar balloon, sent by Gross and Berson from Berlin (1894), registered – 67° C. (– 88°.6 F) at about 18,500 metres (60.696 feet; 11.5 miles).

(2) The laws of the distribution of moisture in the atmosphere.

(3) The velocity of the winds of the upper air. The motion of the balloon last spoken of was about 33 metres (108.3 feet) per second.

(4) The pressure of the atmosphere.

(5) The physiological effects of increased altitude in balloon ascensions (which are made without marked physical exertions on the part of the observer, though not without mental anxiety, probably) have some bearing on the question of life and work at high mountain-stations.

From 3000 to 4000 metres (9842 to 13,123 feet) Biot and Gay-Lussac found the pulse-rate increased by some thirty per cent. Above 5000 metres (16,404 feet) difficulty of breathing and a desire to sleep are manifested. At 8000 metres (26,247 feet) Tissandier (1875) fell in a swoon, and when he awoke he found his two companions (Sivel and Croce-Spinelli) dead beside him.

The purely meteorological data to be acquired by balloon ascents need not be recited here, though they are of the first importance. Dr. Sohncke points them out (in an address delivered before the Royal Academy of Sciences at Munich) in detail, in connection with a brief sketch of the history of the development of our knowledge of the laws of the winds—a capital question. While much is known from pure mathematical and physical theory, from thousands upon thousands of observations at ordinary levels, and from very many at mountain-stations, this fundamental problem is not yet solved. In Dr. Sohncke's words, meteorology is at a standstill. The elevated stations on peaks have given much valuable information, but their data for the upper air are affected by the local topography and by the surrounding ground. The Eiffel tower is, in its way, an ideal high station, though its height is not sufficient.

In order to make further progress, recourse must be had to balloons —both with and without observers.

During the scientific balloon ascents from Munich, the neighboring mountain-stations of Hohenpeissenberg, Hirschberg, and Wendelstein made corresponding observations on many separate occasions. A discussion of all of these showed that in general the mountain temperatures were far from harmonizing with the temperature of the free-air as obtained from the balloon. The latter temperature is, however, that which is wanted for scientific purposes. It can only be obtained from the thermometer-readings at the high-level stations by applying empirical connections which are neither constant nor certain. The disturbing effect of the mountain masses cannot be fully eliminated. Further progress in scientific meteorology appears, then, to be dependent upon data obtained from a series of intelligently planned balloon ascensions, and this conclusion is growing among meteorologists.

Mountain-stations are not fitted to give all the data required of them. Their observations must in many cases be supplemented by records taken in balloons and in many cases it seems desirable to do away with the stations altogether and to depend solely on balloons. No doubt a given sum of money expended in such ascensions would result in a greater benefit to meteorology than if it were used to build and maintain a mountain-station.

Again, a mountain-observatory once established is fixed in position. Balloon ascensions, however, can be made from any chosen spot, and this constitutes a most important scientific advantage.

The conclusions here very briefly stated with regard to the relative advantage of balloons over mountain-observatories hold good also for observations made from *kites*, of which a word will be said. There can be little doubt that future advances in scientific and in practical meteorology (weather predictions, etc.) will be due in large measure to observations made from balloons and from kites, and that the establishment of a large number of permanent mountain-observatories is to be discouraged, both from a scientific and from a practical point of view.

Kites for Scientific Purposes.

Experiments with large kites, used singly or in tandem, have been made and heights of several thousand feet have been reached.

Self-registering meteorological instruments have been devised which are light enough to be lifted by this means.

Wherever there are strong winds this method of investigation promises to be as useful as it is simple and inexpensive, and with skill kites can be raised to the upper winds through almost dead calms below. Mr. W. A. Eddy has sent a single kite to about 1800 feet. At or before the time such an elevation is reached the string becomes too heavy to be lifted, and the method of using kites in tandem consists in lifting the string of the first kite by attaching it to a second. The string of the second kite can again be lifted by using a third, and so on. With nine kites a maximum height of about 5600 feet has been reached.

In strong winds kites have many advantages over captive balloons; and at all times either kites or balloons have some important advantages for meteorological observations over mountain-stations—particularly over high mountains which are covered with snow. Such stations are affected by exceptional local conditions. The snow itself affects the surrounding atmosphere sent up from a valley near a high mountain in a marked degree. A kite or a balloon would certainly experience different conditions from those prevailing about the mountain summit.

Again, mountains suitable for observing stations are not to be found everywhere—whereas balloons and kites can be sent up from any station.

It ought not be forgotten that the first scientific kite-flying was done by Benjamin Franklin so long ago as 1752.

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