36-inch telescope, and the number of stars added, are as follows, omitting from the original number those not seen by me :

	Original.	New.	Total.
V	33	17	50
VI	23	8	31
VII	24	35	59
VIII	61	100	161

The stars of the completed charts fall in the following grades :

8.9	magnitude and brighter,	3
10.11	"	24
12.13	"	51
14.15	"	86
16.17	"	137

The observations were made with a power of 350, on the 36-inch telescope, giving a field of 5′.

LICK OBSERVATORY, July 20, 1894.

(SEVENTEENTH) AWARD OF THE DONOHOE COMET-MEDAL.

The Comet-Medal of the Astronomical Society of the Pacific has been awarded to Professor J. M. SCHAEBERLE for his discovery of an unexpected comet on the negatives of the eclipse of April 16, 1893.

The Committee on the Comet-Medal,

EDWARD S. HOLDEN,
CHAS. BURCKHALTER.

July 24, 1894.

THE SPECTRUM OF MARS.

BY W. W. CAMPBELL.

The spectrum of *Mars* has been observed by several eminent astronomers — RUTHERFURD, SECCHI, JANSSEN, HUGGINS, VOGEL, MAUNDER. These observers had especially in mind the solution of two questions : (*a*) Is there spectroscopic evidence of an *atmosphere* on *Mars?* and (*b*) Is there spectroscopic evidence of *aqueous vapor* in the atmosphere of *Mars?*

The observations made in 1862 in America by RUTHERFURD* did not give an affirmative answer to these questions. The meagre results obtained seem to show that his instrumental equipment was not adapted to the solution of this problem.

The details of JANSSEN'S observations have not been published, so far as I know, but his conclusions are expressed in a letter** read to the French Academy in 1867: "I cannot bring this letter to a close without telling you that I have ascended Mt. Etna for the purpose of making some spectroscopic observations which require a great altitude in order to annul the greater part of the influence of our atmosphere. From these observations and from those which I have made at the observatories of Paris, Marseilles, and Palermo, I believe I can announce to you the presence of aqueous vapor in the atmospheres of *Mars* and *Saturn*."

In 1867 HUGGINS† in England observed lines in the spectrum of *Mars* "apparently coincident with groups of lines which make their appearance when the Sun's light traverses the lower strata of the [Earth's] atmosphere, and which are therefore supposed to be produced by the absorption of gases or vapors existing in our atmosphere. The lines in the spectrum of *Mars* probably indicate the existence of similar matter in the planet's atmosphere."

We have not the dates and details of SECCHI'S observations, but in 1872 he wrote†† that he considered his observations "proved the existence of a Martian atmosphere analogous to our own." However, there appears to be a reasonable doubt as to the sufficiency of his observations.

The most extensive observations on this subject are those made by VOGEL in Germany in 1873. From his observations he considered that "it is definitely settled that *Mars* has an atmosphere whose composition does not differ appreciably from ours, and, especially, the Martian atmosphere must be rich in aqueous vapor."‡

Observations by MAUNDER‡‡ at Greenwich in 1877 confirmed in a general way those made by VOGEL.

---

* *American Journal Science*, Jan. 1863.

** *Comptes Rendus*, Vol. LXIV, page 1304.

† *Monthly Notices Roy. Ast. Soc.*, Vol. XXVII, page 179.

†† *Sugli Spettri prismatici di Corpi celeste*, Rome, 1872.

‡ *Untersuchungen über die Spectra der Planeten*, page 20.

‡‡ *Monthly Notices Roy. Ast. Soc.*, Vol. XXXVIII, page 35.

It is seen that the investigations of five eminent spectroscopists lead them substantially to the same result, viz.: *That Mars' atmosphere is similar to our own.* Their conclusion has been very generally accepted by astronomers. A careful examination of all the published data has shown me that some of the observations were made under circumstances *extremely unfavorable*, and that between the different sets of observations there is not that close agreement which one would like to see. While I believed that *Mars* has an atmosphere and that it contains water vapor, it seemed to me that a repetition of the spectroscopic observations under the very favorable circumstances existing here would be valuable.

Among the favorable circumstances we may mention:

(1) Improved spectroscopic apparatus. The observations mentioned above were made from seventeen to thirty years ago, with spectroscopes comparatively crude.

(2) A telescope of great focal length and correspondingly large aperture. The telescopes used in the early observations were small and short, so that the images of *Mars* formed by them on the slit-plates would be less than one-third as large as that given by the 36-inch equatorial. This is an enormous advantage, both in estimating the relative intensities of spectral lines, and in comparing the intensities of the centres of the lines (corresponding to the centre of *Mars*' disc) with the intensities of the ends of the same lines (corresponding to the limb of *Mars*).

(3) The altitude of the observatory, which eliminates from the problem the absorptive effect of the lower 4200 feet of the Earth's atmosphere, with all its impurities. Most of the old observations were made from near sea-level.

(4) The very dry summer air prevailing here. The average relative humidity is very low at Mount Hamilton for the months of July and August. In many years it is less than 35 per cent. There is no difficulty in selecting nights for observing the spectrum of *Mars* when our relative humidity is not more than 20; quite frequently it is less than 20. This is a very important factor, since in examining *Mars*' spectrum for evidences of aqueous vapor it is very important, as JANSSEN pointed out in 1867, that we eliminate as far as possible the effect of aqueous vapor in our own atmosphere. The observers do not seem to have taken this factor into account (except JANSSEN, the details of whose observations appear to be unpublished). By examining

the contemporary weather data, I find that some of the observations were made when the relative humidity was 81, 85 and even 90. All the principal published observations were made where the average relative humidity at those seasons of the year is something like 80.

(5) The southern location of the observatory and the north declination of *Mars* permit the observations to be made when the planet's altitude is as great as 59°. At an altitude of 59°, the light from *Mars* passes through 1.17 times as much atmosphere as it would if the planet were in the zenith. The most important of the published observations were made when the planet's altitude was only from 21° to 26°. That is, its light passed through from 2.75 to 2.28 times as much of our atmosphere as it would had the planet been in the zenith! While the observers sought to eliminate the effect of our atmosphere and its aqueous vapor by observing the lunar spectrum when the Moon was at the same altitudes, it must be evident that the Martian spectrum was observed at a tremendous disadvantage. One observation was made, for instance, when the altitude of *Mars* was only 24° and the relative humidity of our own atmosphere was 85. The effects of any possible Martian atmosphere would be pretty thoroughly drowned by the effects of the great thickness of our own atmosphere, nearly saturated with moisture.

(6) Finally, we may mention that our knowledge of the spectrum of our own atmosphere has been largely increased in the last few years. THOLLON'S excellent maps, for instance, are of great assistance in this problem.

With all these favorable circumstances, I expected that a confirmation of previous results would be a simple and easy matter.

We shall now state briefly the elements which enter into this problem.

We know by observation that the hemisphere of *Mars* which is turned toward the Sun is bright, and that the hemisphere which is opposite the Sun is dark. The planet, therefore, shines by reflected sunlight. The spectrum of *Mars* must be identical with that of the Sun, except as it is modified by the planet's (supposed) atmosphere.

The highly heated interior of the Sun, constituting its most dense portions, radiates light of all possible wave-lengths: that is, its spectrum is a strictly *continuous* band—not crossed by dark lines. The outer portions of the Sun are gaseous, of very much lower temperature than the inner portions, and made up of the vapors of the chemical elements contained in the Sun. These vapors, mostly those of hydrogen and the metals, constitute a sort of *solar atmosphere.* The light radiated from the hotter interior of the Sun does not pass freely through this surrounding atmosphere. It absorbs some of the rays of every wave-length (but more especially the blue and violet rays). This is called a *general absorption.* It also selects light of *particular* wave-lengths and absorbs that light very strongly, producing the dark lines. The absorption which produces the dark lines is called *selective,* and the lines are called *metallic* lines. The solar spectrum consists of the *continuous spectrum* of the *Sun's interior* modified or interrupted by thousands of (dark) *metallic lines* caused by the *solar atmosphere.*

Our own atmosphere modifies the solar light which passes through it. It exercises both a *general* absorption, which weakens the continuous spectrum, and a *selective* absorption, which introduces at least 1200 additional dark lines. These dark lines—called *telluric* lines—constitute what we may term the spectrum of our atmosphere.

If the planet *Mars* is surrounded by an atmosphere, it no doubt exercises an absorption upon the solar light which enters it. The rays of light coming to us from the planet, originate in the Sun; they pass once through the solar atmosphere; they enter *Mars'* atmosphere, are reflected partly by the planet's surface and partly by the inner strata of its atmosphere, and then pass out through its atmosphere; and they finally reach us by passing once through our atmosphere. The spectrum of *Mars* is, therefore, the combined spectrum of the solar, Martian and terrestrial atmospheres. If it *has* no appreciable atmosphere, the spectrum of the planet is simply the combined spectrum of the solar and terrestrial atmospheres.

The problem before us would be practically insoluble if we did not have a convenient means of eliminating the solar and terrestrial spectra, and leaving only *the Martian spectrum.* Our Moon has no appreciable atmosphere. Consequently, its spectrum is the combined solar and terrestrial spectrum. If we compare the spectra of *Mars* and the Moon when these bodies are at the same altitude above our horizon,—that is when their light traverses the same thickness of terrestrial atmosphere,—and find that they differ in any respect, however slight, such difference must be caused by an atmosphere on *Mars*. If no difference is found to exist, then the spectroscope affords no evidence of such an atmosphere. Thus, the problem resolves itself into a comparison of the Martian and lunar spectra.

THOLLON has found that in the combined solar and terrestrial spectrum three very strong groups of lines are produced by some of the *constant* elements of our atmosphere, probably by the oxygen. These are the FRAUNHOFER groups A, B and α, comprising about 130 separate lines. The presence of these lines indicates the presence of *atmosphere*. If they are *stronger* in the Martian spectrum than in the lunar spectrum, that planet must have an atmosphere.

THOLLON* found other groups of lines, comprising at least 1100 separate lines, produced by the *aqueous vapor* in our air. They have been divided by THOLLON into the following seven groups:

(1)	Wave-lengths	745	to	716	(FRAUNHOFER'S *a*)
(2)	" "	716	"	687	(below B)
(3)	" "	660	"	646	(around Hα)
(4)	" "	635	"	628	(near α)
(5)	" "	597	"	585	(around D)
(6)	" "	578	"	567	(BREWSTER'S δ)
(7)	" "	548	"	542	

The presence of these groups of lines indicates the presence of *aqueous vapor*. If they are *stronger* in the Martian spectrum than in the lunar spectrum, there is *aqueous vapor* in the atmosphere of *Mars*.

Now while all these lines can be observed *individually* in the solar spectrum, owing to the high dispersion which can be used, they can only be observed as groups or bands in the Martian and lunar spectra, on account of the faintness of those spectra and the low dispersion which must be employed.

It is impracticable to observe the groups A, 745–716 and 716–687, which are at the extreme red end of the spectrum, and they will not be further considered. The atmospheric bands B and α are easy to observe in both spectra. The vapor groups of lines require great care in observing, for the reason

* It must not be considered that the credit of this work is due wholly to THOLLON. Many observers, BREWSTER, GLADSTONE, JANSSEN and others, investigated along the same lines. But THOLLON'S work is most complete and his maps are especially convenient and useful.

that, owing to the low dispersion which must be used, the individual lines are not only blended with each other but also with the solar *metallic* lines which lie among them. In the 7th group, for instance, the vapor lines are so much fainter than the neighboring metallic lines that we need not consider that band in the present problem. For the same reasons the 6th group, 578–567, is not a sufficiently sensitive test for aqueous vapor, except in the Earth's atmosphere when the body observed is near the horizon. However, the region of the 6th group was carefully observed in the Martian and lunar spectra on several nights. The 4th group, 635–628, is useless as a test for aqueous vapor, since the faint lines composing it are always overwhelmed by the prominent lines in the atmospheric group α. Only the 3d and 5th groups remain available. Of the 3d group I have not found useful that portion of it between 660 and 653, on account of the presence of the very heavy $H\alpha$ solar lines and other solar lines among the relatively faint vapor lines. I have for my own use divided the rest of the 3d group into three parts, each of which was found useful. The first covers wave-lengths 6515–20 and includes about eight tolerably strong lines, the majority of which are vapor lines. Under all of the dispersions used it was simply a very narrow band or line, which I shall call c'. The second part covers the region 6491–6500. It includes half-a-dozen strong metallic lines and a few strong vapor lines, all, however, blending to form a very strong, narrow band or line, which we shall call c''. The third part is included between 6463 and 6490, which contains a great many vapor lines and a few metallic lines. It formed a band of good width which we shall call c'''.

The 5th group, extending from 597 to 585, I divided into four parts. The first covers wave-lengths 5941–5959; it contains a number of strong aqueous lines and several metallic lines, forming a band which I called d'. The second covers 5928–35; it is strong in neither metallic nor vapor lines. It forms a narrow band which I called d''. The third portion covers 5912–25; it contains a few metallic lines and very many strong vapor lines; I called this region d'''. The fourth covers 5884–5906; it contains the two very strong solar lines D_1 and D_2, several faint solar lines, and a great many vapor lines. It would be a very useful band if the D lines were not contained in it; but I found their presence very troublesome. Let us call this region d^{IV}.

For the reasons given above I confined my observations almost wholly to the groups B, a, c', c'', c''', d', d'', d''' and d^{iv}. Of these, I found that a, c', c''', d', d''' were best suited for observation.

I observed the spectrum of *Mars* on ten nights between June 29 and August 10 of the present year, paying special attention to the nine critical groups of lines just mentioned. On eight of the nights I compared its spectrum with that of the Moon, when these two bodies were at equal distances above the horizon. On two nights, July 24 and 25, when the Moon was near the planet, I turned repeatedly from one spectrum to the other, while, on the former night, the planet passed from altitude 18° to 50°, and on the latter night, from altitude 45° to 55°. The two spectra have been compared when the relative humidity of our atmosphere was only 15 and when it was as high as 55. The observations were made principally with a dense 60° flint prism, with magnifying powers of 13 and 7, and occasionally with a 30° prism and power 13. When the lunar spectrum was examined, the slit of the spectroscope was always shortened so that the lunar spectrum was the same width as the Martian spectrum. The slit was directed always upon the brightest region of the Moon in order that the two spectra should be nearly of the same brightness, which is a very important condition in making reliable comparisons. In a word, the spectra have been compared under a variety of conditions, but with the conditions for the two bodies always identical. The atmospheric and aqueous vapor lines have been seen in both *Mars* and the Moon, decreasing in intensity as these objects got higher and higher in the sky, and the aqueous vapor lines varying in intensity with the amount of moisture in our atmosphere. At all times the spectrum of *Mars* has appeared to be identical with that of the Moon in every respect.

Further, on several occasions when the planet's altitude was large, I examined the critical groups of lines, especially a, to determine whether the ends of the lines, which correspond to the limb of the planet, were stronger than their centres, which correspond to the centre of the disc. The lines appeared to be of uniform intensity throughout, so far as the different intensities of different portions of the surface permitted a safe estimate to be made.

The intensity of the critical bands, a for instance, was appreciably greater when the Moon and *Mars* were only 30° above the horizon than when they were 55°. The relative thicknesses of our atmosphere traversed by the rays when the bodies were at altitudes of 30° and 55° were as 2 to 1.22. If the rays of light from one of the bodies, *Mars* for instance, pass through a unit thickness of our atmosphere, and the rays from the Moon pass through 1½ units, the intensity of a in the spectrum of the latter is certainly greater than in the spectrum of the former. In fact, I am quite confident that a difference of 25 per cent. in the lengths of paths traversed by the rays from the two bodies would cause an appreciable difference in the intensities of their a bands. The accuracy of the observation is greatly increased by the presence of several neighboring metallic lines, which can be used as standards of comparison.

The results of these observations are as follows:

First.—The spectra of *Mars* and our Moon, observed under favorable and identical circumstances, seem to be identical in every respect. The *atmospheric* and *aqueous vapor* bands which were observed in both spectra appear to be produced wholly by the elements of the Earth's atmosphere. The observations, therefore, furnish no evidence whatever of a Martian atmosphere containing aqueous vapor.

Second.—The observations do not prove that *Mars* has *no* atmosphere similar to our own; but they set a superior limit to the *extent* of such an atmosphere. Sunlight, coming to us *via Mars* would pass twice either partially or completely through his atmosphere. If an increase of 25 to 50 per cent. in the thickness of our own atmosphere produces an appreciable effect, a possible Martian atmosphere one-fourth as extensive as our own ought to be detected by the method employed.

Third.—If *Mars* has an atmosphere of appreciable extent, its absorptive effect should be noticeable *especially* at the limb of the planet. My observations do not show an increased absorption at the limb. This portion of the investigation greatly strengthens the view that *Mars* does not have an *extensive* atmosphere.

While I believe that the polar caps on *Mars* are conclusive evidence of an atmosphere and aqueous vapor, I do not consider that they exist in sufficient quantity to be detected by the spectroscope. This view has an important bearing upon the questions relating to the low albedo of the planet, and the well-known brightness of its limb, in both of which respects the planet resembles our Moon.

MOUNT HAMILTON, 1894, August 14.