



XXXIX. Oxygen in the sun

Professor John Trowbridge & C.C. Hutchins

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$$\text{" Resistance " } = \frac{10^{15}}{.00073 \times 2.303} \text{ (C.G.S.) units.}$$

$$\text{" } = 595 \times 10^{15} \text{ (C.G.S.) units.}$$

$$\text{" } = 595 \times 10^6 \text{ ohms.}$$

Some measurements in which brass knobs were used instead of the platinum-foils yielded results similar to those just given. The flame was, however, of a rounded conical form, about 5 millim. high. The knobs were each 1.7 centim. in diameter, the distance between their nearest points being 8 millim. A Daniell cell gave 65 divisions of a deflection on the electrometer-scale.

The results of the observations were plotted-out as described above, and the equations to the curves found by trial. Taking, as before, y to represent the reading on the electrometer-scale at the time t , in minutes, I find :—

With the + pole of the battery to earth, in two different measurements,

$$y = 315 \times 10^{-.0394t - .00148t^2},$$

$$y = 340 \times 10^{-.039t - .00092t^2}.$$

The negative pole put to earth gives

$$y = 313.5 \times 10^{-.0328t - .000395t^2}.$$

These quantities are of the same dimensions as those given above, and need not be discussed further here.

Gordon's College, Aberdeen.

August 1887.

XXXIX. *Oxygen in the Sun.* By Professor JOHN TROWBRIDGE and C. C. HUTCHINS*.

SINCE the time it was announced that hydrogen existed in great abundance in the sun's atmosphere and was a controlling element in its economy, there have been no more interesting questions in solar physics than those touching the presence of other gases in the sun's body and atmosphere; and when we consider the important part that oxygen plays in terrestrial affairs, the great variety of combinations into which it enters, and its high constituent percentage in the composition of the earth itself, a peculiar interest, second to that of no other element perhaps, attaches to its probable presence in the sun.

The investigation of the spectrum of oxygen as a research by itself, and as connected with its presence in the sun, has

* From an advance proof from the Proceedings of the American Academy of Arts and Sciences, vol. xxiii. Communicated by Professor J. Trowbridge, of Harvard University, Cambridge, Mass., U.S.

occupied many eminent physicists ; but the fact that the latest and most complete investigations have left the minds of scientific men still in doubt, has led the writers to take up the question again with more perfect and powerful apparatus and increased facilities, in order, if possible, to add something to the knowledge of the subject.

The question of the existence of oxygen in the sun was first seriously investigated, we believe, by Dr. Henry Draper, who published in the *American Journal of Science* for 1877 and 1879, and in foreign journals, papers accompanied by reproductions of his photographs. Dr. Draper was firmly persuaded of the existence of oxygen in the sun's atmosphere, and based this belief upon the apparent coincidence of the lines of oxygen taken in air with certain bright spaces in the sun's spectrum which appeared upon his photographs.

Prof. John Christopher Draper published a paper in the '*American Journal of Science*' for 1878, in which he stated his conviction that oxygen exists in the sun ; but his line of argument was just the reverse of that of Dr. H. Draper. While the latter apparently proved the existence of oxygen in the sun by the coincidence of its bright lines with bright spaces in the solar spectrum, the former was led to believe that the bright oxygen lines coincided with dark lines in the sun.

Both observers abandoned the old method of eye observation, and took advantage of the improvements in photography to record the oxygen lines upon a sensitive plate. Dr. H. Draper was led to abandon Geissler's tubes filled with oxygen, and to employ the electric spark in common air, on account of the greater brilliancy of the lines, while Prof. J. C. Draper still adhered to tubes filled with rarefied oxygen. The oxygen lines had been mapped by previous observers, notably by Thalén, and Schuster had shown that there were four spectra of oxygen which could be produced under varying conditions of temperature and pressure.

The photographs of Dr. Henry Draper's oxygen spectrum, together with the juxtaposed solar spectrum, were submitted to the French Academy of Sciences in Paris, June 23, 1879, by M. Cornu. From the remarks of M. Faye we make the following extract :—

"Dr. H. Draper has, however, succeeded in discovering oxygen, not in the chromosphere, but in the photosphere, where it discloses itself by bright lines. It is obvious that this gas is dissociated at a depth, and is immediately taken up by multiple combinations in the region and at the temperature of the brilliant surface. I see in these facts the hope of a confirmation, and above all of an extension, of the views I have put forth on the constitution of the sun ; but what-

ever may be the fate that the progress of spectrum analysis reserves to them, I express here my admiration for the discovery of Mr. Draper, and I hope that his results, so well confirmed by the photographic proofs that our learned member, M. Cornu, has shown the Academy, will meet with no delay in being universally accepted by competent judges."

The opinion thus expressed by so eminent an authority as M. Faye testifies to the strength of the evidence brought forward by Dr. Draper. With the exception of Prof. John C. Draper, physicists, in so far as they have expressed their views, have generally accepted the hypothesis of Dr. Draper. No one, to our knowledge, has critically examined the hypothesis of bright lines in the solar spectrum.

The reader of Dr. H. Draper's account of his experiments will remember the difficulties he encountered in obtaining an air-spectrum of sufficient brightness to record itself upon the photographic plate. The time that has elapsed since his work does not seem to have made those difficulties less, and, in spite of all our ingenuity has been able to devise, we have been practically confined to taking the spark in free air or oxygen at atmospheric pressure, notwithstanding the broad and hazy character of the lines under these conditions.

Not to record a long list of failures extending over several months, we will briefly describe the arrangements in their final form.

An alternating current dynamo driven at 2000 revolutions per minute was connected to a commutator of four segments upon a fixed spindle, around which revolved two pairs of brushes. The result of this combination was that the current was very frequently and sharply interrupted. This interrupted current was used to excite three large quantity-coils connected in series. From two to twelve jars were employed as a condenser to the secondary current. The spark was taken between two stout rods of aluminium placed immediately in front of the slit, and the spark passed between them with a deafening rattle, and gave about the light of two candles. We tried Dr. Draper's device of a soapstone compressor for the spark, but in our hands the walls of the soapstone near the spark melted down, and formed a conducting surface over which the current passed.

The photographic apparatus is the large instrument of Professor Rowland,—a concave grating with ruled surface 6×2 inches, mounted upon an iron girder 23 feet long, moving upon two tracks at right angles, as has been previously described by him and others. Sunlight is introduced by a heliostat with mirror silvered on first surface, and an image of the sun formed on the slit by means of a quartz lens

of five feet focus. The method of working with the apparatus so arranged has been as follows.

The points of aluminium being permanently fixed in front of the slit, sunlight is introduced, the camera brought to focus once for all, and set to any required wave-length upon a convenient scale. The photographic plate is then placed in the camera, and a shutter immediately in front is set to expose the upper half of the plate. Exposure for the sun is then made; the sunlight is then shut out, and the shutter moved to cover that part of the plate already exposed, and the lower half exposed. The spark is then started and worked from 15 to 30 minutes. In addition to the spectrum of lines there is a considerable continuous spectrum, which after a time causes fogging of the plates; so there does not seem to be any gain in an exposure of more than half an hour. The feebleness of the air-lines can be judged of when we state that, with the same plate, breadth of slit, &c., we get a metallic spectrum in the arc in ten seconds, strongly photographed. There was sufficient iron present in the electrodes as impurity to give the strongest iron-lines feebly, and these have been of use in determining that no displacement had happened, although, from the nature of the arrangements, such disturbance could hardly occur.

On the negative produced as above indicated the two spectra lie exactly edge to edge, like a vernier and scale, and are in the best possible position for the accurate determination of the position of the air-lines. The original plan contemplated a determination of the wave-lengths of all the air-lines throughout the entire spectrum, but persistently bad weather and other causes have compelled the postponement of the completion of this work, though we are now able to give it complete from wave-length 3740 to wave-length 5030.

The photographic map of the solar spectrum of Professor Rowland has made easy what would otherwise have been an undertaking of extreme labour and difficulty. The best of engraved maps of the violet region of the spectrum to beyond F are comparatively worthless. Even on the elaborate map of Vogel, the result of years of labour, it is difficult to recognize with certainty other than the more prominent lines, and you never feel quite sure of your positions; but we turn to the map of Rowland with the certainty of finding every line in its true order and magnitude, so that what was formerly most difficult has now become very simple, and the position of any well-defined air or metallic line can be read directly, by comparison of the photograph with the map, to the tenth of a wave-length.

We here give a table of wave-lengths as determined from our photograph of the sun and air spectra:—

3749.80	Strong, agrees.	4105.04	Strong.	4327.60	Very faint.
3755.35	"	4105.21	"	4328.42	"
3830.60	Faint and "broad.	4109.76	Very strong.	4330.37	"
3839.275	Dim and broad.	4011.01	Very faint.	4331.20	"
3842.30	Very faint.	4112.16	"	4332.40	Sharp.
3843.00	"	4119.36	Fairly strong.	4336.77	"
3850.70	Faint.	4120.46	Faint.	4345.52	Strong.
3857.40	"	4121.52	"	4347.47	Faint.
3863.80	"	4121.56	"	4347.94	Strong.
3864.90	"	4123.82	Agrees.	4349.30	"
3882.45	Strong.	4132.82	Faint.	4351.40	"
3893.50	Faint.	4133.79	"	4353.70	"
3894.95	"	4145.87	"	4356.62	Faint.
3896.40	"	4147.42	"	4362.90	"
3896.90	"	4151.92	"	4365.40	Faint.
3900.975	Sharp.	4153.57	May agree.	4366.92	Strong.
3902.20	Very faint.	4155.42	Faint.	4369.60	Faint.
3906.00	Sharp.	4156.79	"	4371.40	"
3912.30	Fairly strong.	4164.72	Faint.	4379.70	"
3919.25	Strong, agrees.	4166.72	"	4381.50	"
3935.10	Very faint.	4169.47	Agrees.	4385.30	Very faint.
3936.90	Faint.	4172.12	"	4385.40	"
3938.80	"	4175.72	Band.	4386.50	Nebulous.
3939.80	"	4177.92	Very faint.	4396.30	Faint.
3940.70	"	4179.92	Faint band.	4401.22	"
3941.40	"	4185.32	Very strong.	4415.00	Strong, agrees.
3942.48	Sharp.	4190.00	"	4417.17	"
3946.20	"	4193.77	Very faint.	4421.00	Faint.
3948.10	Very faint.	4198.72	"	4426.00	"
3949.00	{ Sharp, may	4199.22	May agree.	4430.04	"
3951.45	{ agree.	4202.12	"	4431.90	{ Very broad dim
3954.85	"	4205.72	Very faint.	4434.27	band.
3956.175	Strong.	4206.92	Band.	4439.47	Sharp.
3958.10	Strong, agrees.	4209.12	Very faint.	4443.00	Broad dim band.
3958.90	Faint.	4214.92	"	4443.00	"
3959.975	Sharp.	4223.17	Faint on band,	4447.09	Very strong.
3963.70	"	4224.92	" "	4452.40	Sharp.
3968.70	"	4225.92	" "	4456.00	Faint and sharp.
3973.60	Strong.	4228.52	Band.	4459.90	Faint.
3981.40	"	4236.67	"	4465.40	Sharp.
3982.97	Faint.	4241.92	"	4466.00	"
3992.87	Sharp, agrees.	4249.02	"	4468.02	Very faint.
3995.10	Very strong.	4253.42	Very faint.	4469.50	"
3998.81	{ Very faint, may	4266.32	Faint.	4472.90	"
4008.39	{ agree.	4271.22	"	4477.87	Broad and faint.
4011.34	Faint.	4274.82	Very faint.	4481.87	Sharp.
4035.34	Band.	4277.90	Faint.	4487.94	"
4041.39	Band.	4279.90	Fairly strong.	4489.90	Faint.
4066.84	Faint.	4282.40	Faint.	4496.97	Sharp.
4070.24	{ Strong, may	4291.90	"	4498.95	Faint.
4072.34	{ agree.	4303.80	Very faint.	4503.05	Fairly strong.
4076.19	"	4305.67	"	4507.72	"
4078.83	Faint, agrees.	4309.87	Faint and sharp.	4511.85	Sharp.
4085.24	"	4312.72	"	4520.50	{ Strong, may
4085.84	"	4315.52	"	4544.50	{ agree.
4088.64	Faint.	4317.20	Strong.	4565.97	Fairly strong.
4093.09	"	4319.50	"	4572.02	Sharp.
4097.49	"	4322.80	{ Faint, may	4575.55	Sharp, agrees.
		4323.90	{ agree.	4577.50	Sharp.
		4325.90	Very faint.	4578.55	"
			Agrees.	4582.32	"

4583.15	Very strong.	4676.40	{ Faint, may agree.	4822.12	Faint.
4587.45	Sharp.	4681.10	Very faint.	4825.12	Faint, may agree.
4588.05	"	4682.40	"	4842.00	Faint but sharp.
4588.92	Very faint.	4687.15	"	4863.92	"
4589.40	"	4688.80	"	4877.70	Faint.
4590.00	"	4691.40	"	4878.80	Very faint.
4590.95	{ Strong, may agree.	4694.15	Strong.	4879.90	"
4592.00	"	4695.15	Faint.	4891.27	"
4592.95	Strong.	4696.70	Very faint.	4894.90	"
4596.20	"	4699.40	Broad and faint.	4898.70	"
4601.37	Very strong.	4700.40	Faint.	4906.77	"
4607.20	"	4701.65	"	4907.67	"
4609.45	{ Sharp, may agree.	4703.02	Agrees.	4913.69	Sharp.
4612.75	Faint.	4705.42	Fairly strong.	4915.12	Sharp, but faint.
4614.05	Strong, agrees.	4710.20	"	4916.86	Sharp.
4621.42	Strong.	4712.87	Very faint.	4936.86	Band.
4630.73	Very strong.	4719.92	"	4940.85	Sharp.
4634.00	Sharp.	4731.27	"	4945.01	"
4638.90	Strong.	4733.95	"	4945.81	"
4640.75	Rather faint.	4740.20	"	4950.21	"
4641.90	Fairly strong.	4744.20	"	4951.41	Nebulous band.
4643.45	Strong.	4753.82	Sharp.	4953.85	Sharp, agrees.
4645.40	Faint.	4755.16	"	4955.16	"
4649.25	Strong.	4760.07	"	4960.16	"
4651.02	Fairly strong.	4763.82	"	4969.85	"
4654.10	Faint.	4771.82	"	4972.85	"
4654.85	"	4775.07	"	4979.90	"
4655.90	Faint band.	4782.62	Very strong.	4983.06	{ Sharp, may agree.
4658.05	Very faint.	4788.27	Very faint.	4993.95	Faint.
4659.60	"	4791.32	Sharp, agrees.	4997.60	"
4665.70	Faint.	4798.97	Very faint.	4999.31	Agrees.
4667.55	"	4800.82	"	5001.55	Faint.
4671.65	"	4802.37	Very strong.	5011.06	Sharp, agrees.
4672.30	"	4808.94	Very faint.	5012.50	Faint.
4673.30	Very faint.	4810.02	Faint.	5018.55	May agree.
4674.95	{ Faint, may agree.	4811.92	"	5022.95	{ Faint, may agree.
		4813.52	"	5033.85	Very faint.
		4816.60	Very strong.		
		4820.90	Faint.		

In regard to the accuracy that may be expected of the above positions, we feel sure that few of them are wrong by more than a tenth of a wave-length, and these are of the class "Very faint," or "Broad and nebulous." The better defined lines we believe to be correct to within less than the above amount. The method of comparison we have used admits of much greater accuracy than this, but the ill-defined character of the air-lines puts a limit to their accurate placing. Compared with Thalén's positions, they should be credited with ten times the accuracy at least. Some of Thalén's bands are resolved into two or more in our instrument.

Prof. John C. Draper projected his spectra upon a scale of wave-lengths by means of a stereopticon—a method which does not inspire confidence in his results, when we consider the distortion produced by projecting-lenses.

The scientific world seems largely to have accepted the

wave-lengths of Ångström and Thalén as final. One eminent authority speaks of them as the "ne plus ultra" of spectroscopic accuracy; and any attempt to revise or correct them may be looked upon as presumptuous. However, we believe the time has arrived when the whole of Thalén's work on metallic spectra must be re-examined. It is safe to say that he has tabulated not more than one line in many metals where several exist, and his positions are occasionally wrong by as much as two wave-lengths.

As yet no approach to the accuracy with which the solar spectrum has been delineated has been attempted in metallic spectra—a remarkable fact, when we consider that the chief interest that attaches to the study of the solar spectrum is in its connexion with spectra of terrestrial elements.

The test of the existence of oxygen in the sun is the coincidence of the bright lines of the spectrum of oxygen with bright lines or with dark lines of the solar spectrum. If the bright lines of any metallic vapour formed in the electric arc or the electric spark coincide with the dark lines of the solar spectrum which is photographed directly above the spectrum of the metal on the same sensitive plate, the evidence is usually considered conclusive in regard to the existence of the metal in the sun. In the case of iron, where hundreds of lines of the metal coincide with dark lines in the solar spectrum, not only in exact position but in general grouping and character, the evidence cannot be doubted by any one who has carefully examined it. When a majority of the lines of any metal coincide with dark lines in the solar spectrum under high dispersion, not only in position but in grouping, while a few of the metal lines have no representatives in the solar spectrum, there is a probability that the corresponding lines wanting in the sun have been obliterated by superposed lines or bands of other metals. In our paper "On the Existence of Carbon in the Sun," we shall call attention to a case of such obliteration. It is probable, also, that the non-appearance of certain lines in the sun may be due to certain conditions of temperature. We shall discuss this point more fully in the paper on Carbon, above referred to.

The same remarks apply to the coincidence of the lines of any element with the supposed bright spaces in the sun. The value of the test of coincidence increases with the number of coincidences. If an element has only two or three lines, and these two or three agree in position with dark lines in the solar spectrum, the evidence of the existence of the element in the sun is not conclusive. It is supported, however, if there is any striking peculiarity in the lines of the

element which is reproduced in the corresponding lines in the solar spectrum. Thus the nebulous character of the lines of magnesium is perfectly reproduced in the corresponding lines in the solar spectrum. The test of coincidence, therefore, requires primarily a normal spectrum, and the highest possible dispersion. The earlier observers were limited to instruments of small dispersion, and the entire number of lines observed in the solar spectrum was small compared with that given by the best modern apparatus. The chances for an apparent coincidence were therefore much greater, and evidence of a very misleading character could be obtained.

In Dr. H. Draper's published photograph, the coincidence of the greater part of the oxygen lines with bright bands in the solar spectrum is quite striking; and it is not a matter for surprise that he was led to conclude the connexion between the two spectra to be a physical one, and to announce the existence of oxygen in the sun as proved. Instances are not infrequent where instrumental imperfection or lack of power has led to results unsupported by later and more powerful research. Witness the spots of Venus of the older observers. Now when we apply to the spectra of the sun and oxygen a dispersion and definition that show the minute detail of each, the "bright bands" at once vanish, or no longer appear as such, and all the apparent connexion between them and the oxygen lines disappears also. The bright bands of Dr. H. Draper's spectrum are found to be occupied by numerous dark lines, of various degrees of intensity; but the hypothesis of Prof. J. C. Draper, that these are the true representatives of the oxygen lines, is rendered untenable by the lack of any systematic connexion between the two. It happens quite frequently that an oxygen line falls centrally upon the space between two dark lines of the solar spectrum, but not more frequently than we might expect as a matter of chance, when we consider the vast number of lines and spaces; and the fact that the spaces are no brighter than the surrounding background of the solar spectrum would not seem to permit of their interpretation as bright lines.

The subject of bright lines in the solar spectrum is one upon which men will probably differ, and we have sought information upon it. Of course there is no *à priori* reason why such bright lines should not exist, as they do in many stars; but we have photographed the sun's spectrum every day that the sun has shone for nearly five months, without finding a line that could with certainty be pronounced brighter than its neighbours; and it must be admitted that the photograph is the best of photometers in such a case.

In regard to the other three spectra of oxygen of Schuster we have nothing to say ; but so far as concerns the spark spectrum in air and the solar spectrum from wave-lengths 3749.8 to 5033.85 we can safely affirm that there is no physical connexion between them.

XL. *On the Existence of Carbon in the Sun.*

By Professor JOHN TROWBRIDGE and C. C. HUTCHINS*.

FROM the presence of absorption-bands in the solar spectrum at high altitudes, Captain Abney has been led to believe in the existence of certain hydrocarbons between the earth and the sun ; and Siemens's theory of the conservation of solar energy depends upon the supposed existence of carbon vapour in interplanetary space. It is not our purpose to discuss Abney's observations, or the truth of Siemens's hypothesis. We wish to call attention to the remarkable character of the carbon spectrum, formed by the Voltaic arc in air between carbon terminals ; and to draw attention to the evidence presented by the juxtaposed solar spectrum of the existence of carbon in the sun.

In our early experiments the carbon terminals between which the Voltaic arc was formed were heated several hours, while a stream of chlorine gas was passed over them. This operation was not entirely successful in removing metallic impurities. Subsequently we discovered that the spectra of these impurities could be readily distinguished from the marked fluted carbon spectrum, and we therefore employed the ordinary compressed carbon sticks employed in electric lighting.

For our work the nicest adjustment of slit was necessary, in order that no displacement of spectrum lines could possibly occur when the carbon spectrum was photographed in juxtaposition with the solar spectrum. This was accomplished by the use of a slit, the jaws of which opened equally.

One of Rowland's concave gratings, of 21 feet 6 inches in curvature and 14,000 lines to the inch, was employed. In order to avoid any possible displacement of the photographic camera during the operation of photographing the carbon spectrum immediately below the solar spectrum, a drop-shutter was arranged directly in front of the sensitive plate, the movement of which was independent of any movement

* From an advance proof from the Proceedings of the American Academy of Arts and Sciences, vol. xxiii. Communicated by Professor J. Trowbridge, of Harvard University, Cambridge, Mass., U.S.