



THE
ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME XL

OCTOBER 1914

NUMBER 3

AN APPLICATION OF INTERFERENCE TO THE STUDY
OF THE ORION NEBULA

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We published in 1911¹ an account of the principle involved in our investigations and of the preliminary attempts that we made to apply interference methods to the study of nebulae.

In 1912 and especially in 1914 we continued these researches and we were able to get a part of the results which we set out to obtain. It should be remembered that the method consists in producing, with the light from the nebula, interference fringes formed at infinity (rings of a thin sheet of air between parallel silvered planes). These rings are projected on a photographic plate which records them; on the other hand, it is arranged so as not to confuse the radiations sent out by different points of the nebula; that is, a clear image of the nebula is obtained on the same plate with the rings. The latter are therefore visible on the surface of the nebula.

DESCRIPTION OF THE DIFFERENT PARTS OF THE APPARATUS

The telescope.—The entire interferential arrangement was mounted on the reflecting telescope of the Observatory of Marseilles, of which the glass mirror, figured by Foucault in 1862, has

¹ Ch. Fabry and H. Buisson, *Astrophysical Journal*, 33, 406, 1911.

a diameter of 80 cm and a focal length of 4.50 m. The telescope is furnished with a driving mechanism worked by electricity, as well as a slow motion in hour angle. To follow the star during the photographic exposure, an objective of 3 m focus and an eyepiece, forming a refracting telescope, have been attached to the tube of the reflector.

The interferometer.—The arrangement shown in section in Fig. 1, for producing and projecting the interference fringes, forms a compact piece which is placed at the open end of the telescope tube,

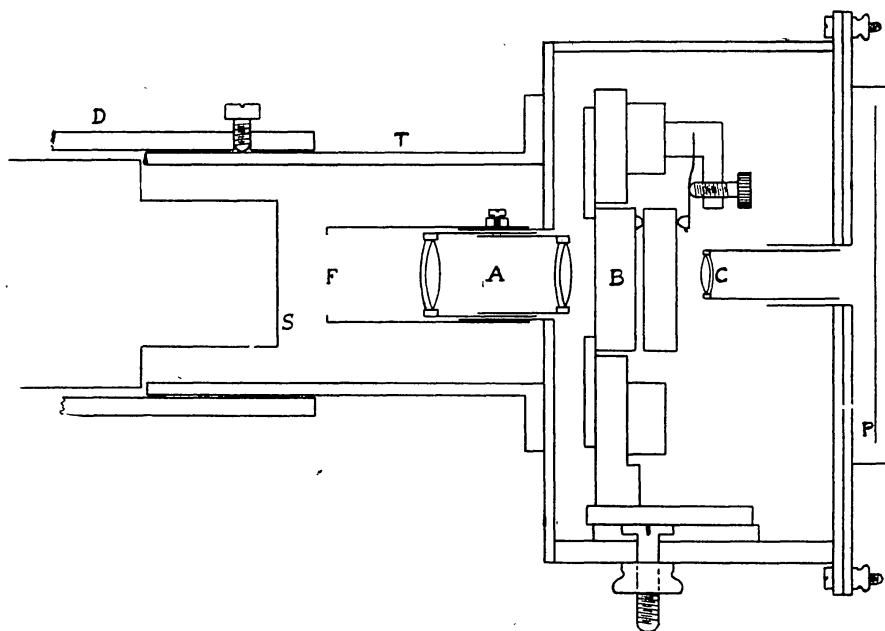


FIG. 1. (About $\frac{2}{3}$ actual size)

centered on the axis of the mirror in such a way that the light reaches it without any additional reflection. This arrangement cuts off a little of the incident light, but only a rectangle 11×14 cm, or $1/30$ of the surface of the mirror.

The étalon is composed of two plates of glass 4 cm in diameter and 1 cm thick, the adjacent surfaces of which are silvered and held parallel by three metal blocks of equal thickness. The exact adjustment to parallelism is made by the pressure of three springs, regulated by means of screws. We used thicknesses from 0.1 mm

to 3 mm. For the smallest thicknesses, the separation was produced by three short lengths of wire cut in succession from the same piece. Greater thicknesses were obtained either with small fragments of steel rod, or better, to avoid expansion, with blocks of invar.[‡]

The quality of the silvering is of primary importance. We obtained it by cathodic projection, following a method which permitted us to obtain at once exactly and very rapidly the desired thickness of silver. As soon as one plate has been prepared, its transparency and its reflecting power are measured. According to circumstances, we used two sets of silvered surfaces to form the étalon. In the first pair each surface transmitted 0.15 and reflected 0.74 of the incident light; in the other pair, these numbers were 0.30 and 0.60, these values referring to the green radiation of mercury.

After reflection from the mirror of the telescope, the light coming from the nebula forms the image in the focal plane F . It next passes through a pair of lenses A , forming an optical system of short focal length, the focus of which coincides with F . This system is formed by two achromatic lenses of uviol glass in order to avoid the absorption of ordinary flint. Each one of them has a focal length of 86 mm and a diameter of 19 mm and they are 40 mm apart. This whole arrangement is calculated in such a manner that it may have a given focal length (56 mm) and that in the interior of a field with a diameter of 10' the light reflected from the large mirror shall be completely utilized. The first lens performs the office of field-glass at a distance of only 30 mm from the real image; and diminishes the size of the pencil of rays on the second lens.

The combination consisting of the mirror and the lenses A forms a non-focal system, whose angular magnifying power is 80. In leaving A the light of the nebula seems to proceed from a star at infinity, enlarged angularly 80 times; in addition the bundle of

[‡] The blocks were cut by M. Jobin, who gave them a very satisfactory form and who obtained in every case exactly the desired thickness. We shall offer an explanation in the near future of the technique of obtaining the silverings as well as the details of construction of the étalons.

rays passes through the ocular ring of which the diameter is only $1/80$ of that of the mirror. It is there that the interference apparatus *B* is placed, immediately followed by the achromatic objective *C*, also of uviol glass, having a diameter of 10 mm and 45 mm focal length. In the focal plane of this objective is the photographic plate *P*. On it we get at the same time the sharp image of the rings (which have not been changed in any way by anything in front of the interference apparatus) and the image of the nebula 80 times larger than if the objective *C* were pointed directly at the sky.

There also appears on the plate the image of two cross-wires, placed at *F* in the focal plane of the mirror, to serve as reference lines. The étalon, the lenses *A*, the objective *C*, the reticle, and the plate-holder are fitted into a metallic box shown in the cut in Fig. 1. This box is attached to the tube *T* which fits into the socket *D*, supported by the frame of the telescope tube. This whole assemblage of parts, which weighs only 4.5 kg, and which takes the place ordinarily occupied by the totally reflecting prism in the Newtonian arrangement, can be taken out and replaced easily.

ADJUSTMENT. COMPARISON RINGS

Certain of the adjustments are made once for all; others should be made anew before each observation. The focusing of the objective *C* on the photographic plate, and the adjustment of the reticle, in such a way that its image is formed on the plate by the lenses *A* and *C*, are accomplished in the laboratory by artificial light.

On the telescope, the setting of the tube *T* (Fig. 1) is determined so that a clear image of the stars is also shown on the plate. This brings the focus of the mirror into coincidence with that of the system *A*. This arrangement, like the preceding ones, is independent of the interference apparatus and is made before the latter is put in place.

Before each observation, the parallelism of the silvered surfaces of the étalon is verified, and it is oriented in the box in such a way that the center of the rings coincides as exactly as possible with the crossed threads of the reticle. This arrangement and the

putting into place of the étalon is performed while the apparatus is taken out of the telescope and illuminated by monochromatic light from a mercury-vapor lamp. Before returning the apparatus to place on the telescope, observations are taken of the coincidences among the rings of the various mercury radiations, which give the exact order of interference of each ring.¹

To measure the interferential photographs of the nebula, it is necessary to have a system of rings, obtained under identical conditions, but with a known monochromatic radiation. This system of rings plays a rôle analogous to the comparison spectrum in ordinary spectroscopes, but, while in the latter case the comparison spectrum and the spectrum to be measured must be made on the same plate, to avoid all displacement, on the other hand the system of comparison rings can be made on a separate plate. The interferential apparatus only must remain unchanged.

A photograph of the comparison rings is made before the exposure on the nebula and another after exposure, leaving the whole apparatus in place on the telescope. At the moment when we wish to make the comparison photographs, we place in the center of the tube of the telescope, about one meter from the opening, a screen of white paper 30 cm in diameter, which is lighted by a mercury lamp held by hand at the opening of the tube. Since the Observatory is supplied only with alternating current, the form of lamp constructed by M. Tian² was employed. The lamp is inclosed in a wooden box having a round opening 4 cm in diameter. A glass cell 2.5 mm thick is placed before the opening and contains a weak solution of chromate of potassium intended to absorb the radiations of short wave-length. Since the plates used are practically insensible to green and yellow, only the ray λ 4358 remains to produce the rings. The exposure is about ten seconds.

The necessary exposure for photographing the interference rings of the nebula depends on the radiation employed and the

¹ A. Perot and Ch. Fabry, *Annales de chimie et de physique* (7), 16, 289, 1899. An explanation of the nature of interference rings by silvered planes will be found in Vol. 15 of the *Records* of the International Bureau of Weights and Measures.

² *Journal de physique* (5), 3, 486, 1913.

thickness of the silverings. Our plates were made with exposures of from one to two hours.

After the preliminary trials, the photographing of interference rings was begun on January 27, 1914, and was continued until March 12; we were able to make 15 plates, some with the radiation H_γ using étalons 1 mm and 2 mm thick, others on the ultra-violet group λ 3728, with thicknesses increasing from 0.13 mm to 2.8 mm.

The accompanying Table I gives a list of all the plates; it gives the date, the radiation used, the thickness and kind of substances separating the silvered surfaces, and finally the exposure-time.

TABLE I
LIST OF PLATES

Date 1914	Radiation Used	Thickness	Blocks	Exposure
January 27.....	$H_\gamma + H_\beta$	1 mm	Steel	1½ hours
28.....	$H_\gamma + H_\beta$	2 mm	"	" "
30.....	H_γ	1 mm	"	1 hour
31.....	3728	1 mm	"	1½ hours
February 2.....	"	110 μ	Mica	" "
13.....	"	130 μ	Wire	" "
14.....	H_γ	1 mm	Invar	" "
16.....	3728	1 mm	"	1¾ hours
28.....	H_γ	2 mm	"	2 "
March 2.....	3728	0.64 mm	"	" "
3.....	"	2 mm	"	" "
5.....	"	2.8 mm	"	" "
7.....	H_γ	2 mm	"	" "
12.....	H_γ	1 mm	"	" "

Plate VII reproduces two of the photographs obtained, that of January 31, with the line λ 3728, the other of March 12, with H_γ . They are negatives, that is, the reproductions are identical with the original photographs, save for enlargement.

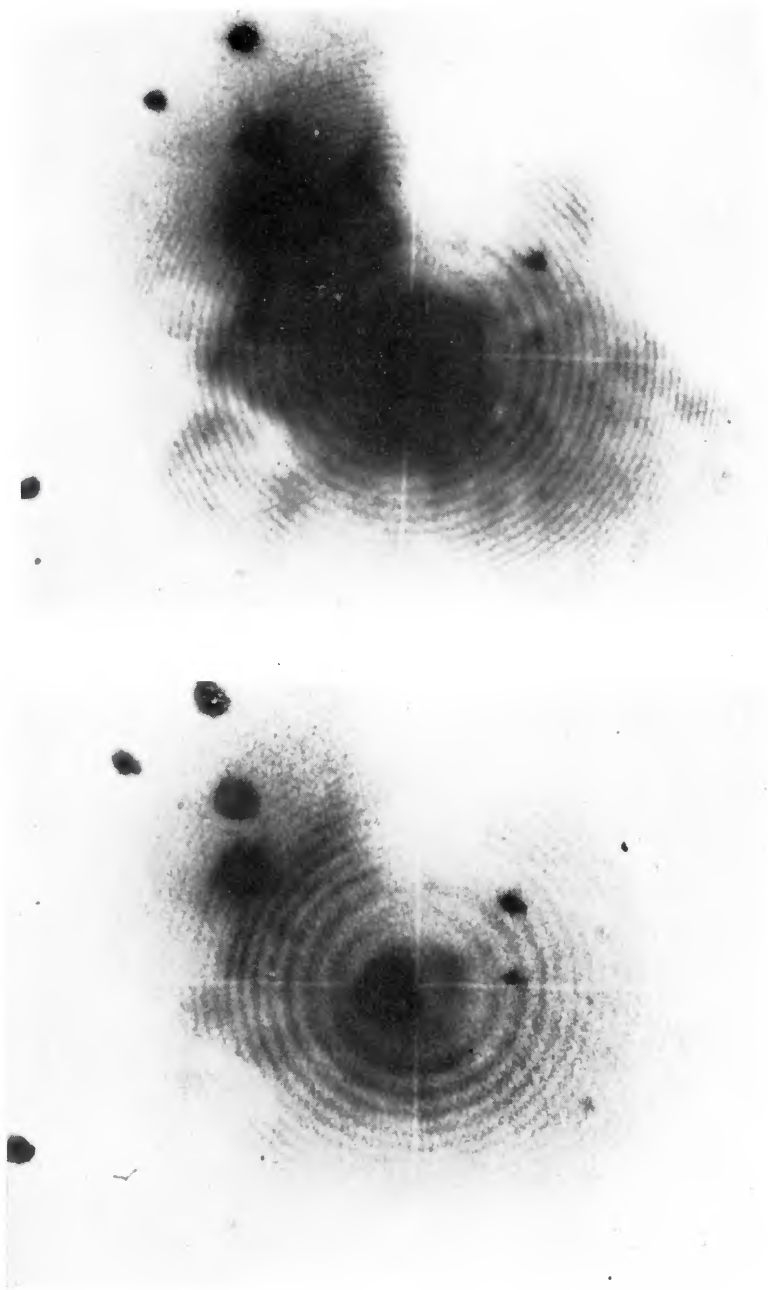
PRELIMINARY STUDY OF THE SPECTRUM. ABSORBING FILTERS

Before beginning the study of the interference rings, we wished to have a personal and direct knowledge of the spectrum of the nebula and of the relative intensity of the various lines. The publications which we found on this subject lack precision and are sometimes contradictory, which is accounted for by the unequal absorption of the different apparatus used and by the different

PLATE VII

South

South



λ 3728

H γ

properties of the photographic plates. We constructed a spectroscope entirely of quartz, very compact and effective as a light-gatherer, the slit of which can be placed at the direct focus of the large mirror. Two 60° quartz prisms, one right-handed and the other left-handed, have square faces 3 cm on a side; the objectives of quartz are 2.5 cm in diameter and 9 cm in focal length. The whole apparatus is attached to a tube identical with that of Fig. 1, fitting into the socket of the telescope. It weighs only 2.7 kg and intercepts but $1/20$ of the incident light.

On the Lumière Sigma plates the ultra-violet line λ 3728, not resolved by the spectroscope, is altogether the most intense; the next is the line H_γ ; the hydrogen lines of shorter wave-length and the helium lines are much feebler. The group $\lambda\lambda$ 4861-4959-5006, composed of H_β and two lines of unknown origin, give a perceptible image on the plates.

In our experiments with the interference rings, we have isolated a radiation by absorbing filters as much as possible. The choice of these filters must be made with a great deal of care in order not to weaken the intensity of the line under examination and in order also to diminish as much as possible the intensity of the other lines. We have tried to obtain the most favorable filters by making exact laboratory measurements of the power of transmission. We

TABLE II

λ	Transmission
3728.....	0.00
4046.....	0.20
4340.....	0.40
4861.....	0.01

employed two groups of filters, one in our study of the line H_γ , the other for the double ultra-violet line. To isolate the line H_γ , the whole ultra-violet end and in particular the line λ 3728 must be weakened; it is necessary also to weaken the green group 4861-5006. The combination employed consists of a Wratten filter of esculin to eliminate the ultra-violet and a Wratten filter *D* (probably a methyl-violet one) which eliminates the green. The transmissive powers of this combination for certain radiations are given in Table II.

To isolate the line λ 3728, the whole visible portion must be eliminated. Violet and blue are eliminated by a screen of nitrosodimethyl aniline. A fuchsine filter stops the green. These filters are obtained by bathing fixed photographic plates in aqueous solutions. We performed a series of experiments by using solutions of different degrees of concentration, and we chose those which yielded the best results. The transmissive powers are given in Table III.

TABLE III

λ	Transmission
3728.....	0.50
4046.....	0.14
4340.....	0.01
4861.....	0.00

The filters are put at *S* (Fig. 1) a little in front of the reticle. They are placed at the end of a tube which enters the socket *D* and which permits their interchange without modifying the rest of the installation. The same combination of filters which we used for H_{γ} was employed to photograph the comparison rings with mercury light.

METHOD OF MEASUREMENT

We are now in possession of three photographs, one from the nebula, and the other two obtained before and after, with the violet line of mercury. Since we know the wave-length of the mercury line, the problem is to determine the wave-length of the radiation which has produced the rings of the nebula. According to the circumstances, this radiation may be a known line like the lines of hydrogen, whose wave-length, however, is modified by the relative motion and will serve to measure the radial velocity, or else it may be a radiation of an unknown element whose wave-length must be determined. The problem of measurement is the same in both cases.

If the nebula has only a motion of translation, the wave-length of a radiation will be the same for all points, the rings are perfectly circular, and the problem is very simple. The diameters of the circles can be measured without reference to the location of their center. Matters are more complex if there are differences of

radial velocity from point to point, because then we can no longer speak of a single value of the wave-length, the rings are deformed, and every point must be defined with respect to the normal to the silvered surfaces (the center of the mercury rings). This set of measurements will give the wave-lengths at the several points and consequently also the distribution of the radial velocities.

Let us examine first the case where there is only a motion of the whole. One of the mercury photographs is placed on a comparator, and the diameters of the successive rings are measured, for example the first five. Let N be the number of the order of the smallest ring measured; it is a whole number which is always known from the observation of coincidences made before the photographic exposures. The problem is to find the order of interference at the center, which can be formulated as $N + \epsilon$. The semidiameters ρ measured from the center obey the law $K\rho^2 = N + \epsilon$.

K is a constant and takes successively the values 0, 1, 2, 3, 4, beginning with the central ring. Combining the five equations which result from the measurement of the five rings, ϵ is calculated together with the constant K . This last quantity can be deduced from the data furnished by the apparatus, but it is more correct to obtain it directly on the plate. The order of interference $N + \epsilon$ is thus determined within a few thousandths of a fringe.

We operate in the same manner on the second mercury plate. We should find precisely the same value for the order of interference if there were no change in the thickness of the étalon or in the index of refraction of the air. In point of fact, the two values obtained differ very little indeed when an étalon with invar blocks has been used. The difference is often less than one-hundredth of a ring and never surpasses 0.03, although the two plates may have been obtained at an interval of two hours and no precaution was taken to eliminate variations of temperature. The average of the two values found is adopted as the value of the order of interference of the violet mercury light.

The plate of the nebula is measured in the same manner. The whole number of the order of interference results from an approximate knowledge of the wave-length of the radiation under observation. The fractional figure is obtained as before by the

measurement of the ring diameters; the corresponding constant K may be deduced from that of the mercury by the observation that it varies in inverse ratio with the wave-lengths. Knowledge of the order of interference in mercury light and of the nebula yields immediately the ratio of the two wave-lengths and consequently that of the radiation of the nebula.

In reality there are differences of radial velocity from point to point and the measurements can only be made point by point. The first thing to be determined in the photograph of the nebula is the foot of the normal to the silvered surfaces whose position on the mercury photographs is defined by the center of the rings. It is in order to correlate the position of this point on our two classes of photographs that we have provided the reticle whose image is reproduced on the photographic plate.

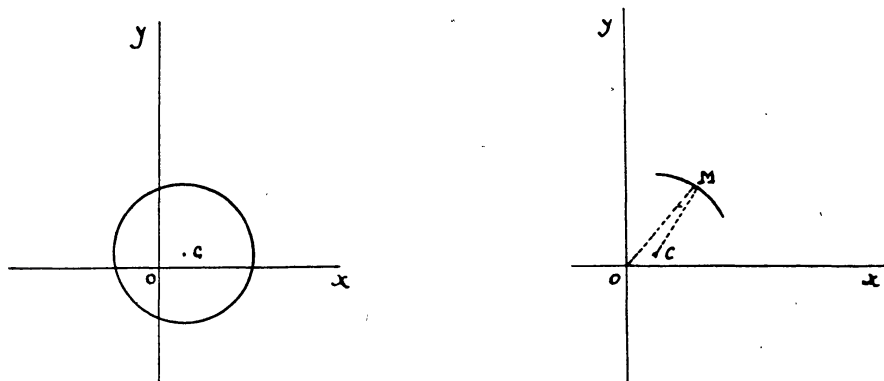


FIG. 2

On the mercury prints the center is determined in the following manner. Let Ox and Oy be the images of the threads of the reticle, and C the center of the rings (Fig. 2). We first orient the print on the comparator in such fashion that the displacement shall be parallel with Ox . With a thread parallel to Oy we then successively set on the two edges of the ring and Oy ; from these measurements we deduce the distance from the point C to the axis Oy , that is, the abscissa of the point C with respect to the system of axes xOy . To increase precision, measurements are made on the first five rings. Operating in the same fashion after turning the plate 90° , we obtain the ordinate of the point C .

These co-ordinates, now known, are registered without alteration upon the photograph of the nebula where they determine the foot of the normal to the silvered surfaces.

Passing to the photograph of the nebula we measure, in a known direction from the point O , the distance OM from the origin of the co-ordinates to a point M of one ring. We shall have to deduce the wave-length λ' of the radiation which produced the ring at M . For this purpose we calculate the distance ρ' from the point M to the point C . This is easy because the co-ordinates of these two points are known. The calculation is simplified by the fact that points O and C are very near to each other and hence ρ' differs from OM only by a small amount. Let N' be the known order of interference of the ring which passes through M . $N' + \epsilon' = P'$ is the order of interference which we should have at the point C if the wave-length everywhere had the same value λ' which it had at M . We then have

$$\epsilon' = K' \rho'^2.$$

K' has the same significance as before and is related to K by the formula

$$K' = K \frac{\lambda}{\lambda'}.$$

On the other hand, we know the order of interference $P = N + \epsilon$ which the mercury line λ yields at the center, and we thus have for the desired wave-length the value

$$\lambda' = \lambda \frac{P}{P'}.$$

This measurement can be made point by point on every ring, and from it we deduce the chart of the radial velocities in the nebula, as we shall see.

For these measures we used a comparator constructed by Gaertner of Chicago, after a slight modification of it. On the carriage moved by the screw, a vertical plate-holder is placed, which can turn in its own plane and which carries a divided circle. The reticle of the microscope which serves to make the settings

has but a single wire for the measurement of the mercury rings; whereas for the rings of the nebula, where we must take not a tangent but a definite point, the intersection of two cross-hairs is used.

THE STUDY OF THE RADIAL VELOCITIES

Absolute measurements of radial velocities can be made only by means of radiations capable of emission from terrestrial sources. With radiations of unknown origin nothing but a differential study of the velocities of different points can be accomplished.

For a known radiation we have employed the line H_γ of hydrogen. The measurements were made on photographs that were obtained with an étalon 1 mm thick, that is to say, with rings of the approximate order of 4600. They have been conducted in such a way as to eliminate the wave-length of the mercury line and to compare the radiation of the nebula with that of a hydrogen tube. For this purpose with the same étalon and with the same silvered surfaces, a comparison is made between the mercury line and the artificial line of hydrogen. The whole arrangement represented in Fig. 1 is transported to the laboratory. Here one photograph is taken with the mercury line and one with the line H_γ separated from the other hydrogen lines by a dispersive apparatus. This group of photographs gives the wave-length of H_γ , the value 4338.341 for the mercury line being used. The photograph of the nebula is calculated as we indicated above, the same value for the wave-length of mercury being used. The radial velocity at each point of the nebula results from a comparison between the wave-length at this point and the wave-length which has been found in the laboratory for H_γ . The result is independent of the value adopted for the mercury line, since this has served only as a convenient intermediary, on account of its great intensity.

With rings of the order 4600 a radial velocity of 1 km per second produces a change in the order of interference equal to 0.015, that is, a change of the same order of magnitude as the probable error of a single measurement. To give an idea of the effect of radial velocities on interference rings, let us consider the motion of the earth in its orbit, which produces the maximum radial velocity when the nebula is at 90° from the sun, i.e., in quadrature;

between one quadrature and the next, the difference of radial velocity is 60 km per second. This is equivalent to a change of one whole ring in the interference rings. If it were possible to photograph the rings every day between the two quadratures we should see them contract until every ring took the place of the next preceding one.

In performing the calculations as we have indicated, the absolute radial velocity with respect to the observer is obtained for every point which has been measured on the nebula. An average of these velocities can be taken for a definite surface and can then be corrected for the velocity of the earth in order to obtain the average velocity of the nebula with respect to the sun. On the other hand, the internal movements of the nebula will be represented by calculating the velocities of its several points with respect to this mean velocity.

The differential study of velocities can also be made on photographs obtained with the line of unknown origin λ 3728. This would not permit one to obtain absolute values. This line is finer than H_{γ} ; it therefore permits the employment of fringes of a higher order, upon which the effect of radial velocities is even greater. Since the line is double, we shall choose the thickness of the étalon in such a manner as to have the two systems of rings coincide.

In this kind of study the interference method presents the advantage of yielding the radial velocities of the whole surface of the nebula simultaneously, whereas an ordinary spectroscope permits us to study only those points which are projected on the slit.

Results.—All our prints of the nebula were made with the rings centered upon the region of the trapezium; we utilized the first seven or eight rings. This permits us to study the radial velocity within a circle of about 4' diameter. The luminous intensity is nevertheless sufficient to permit more extensive measurements, but for this it would be necessary to place the center of the rings in other regions of the nebula, because the measurements lose their precision when rings too remote from the center are utilized.

In the region surrounding the trapezium, the mean radial velocity with respect to the sun is +15.8 km per second; i.e., the

nebula is receding from the sun. This number is the average for values found for 58 points distributed in 12 directions about the trapezium in a radius of about $2'$.¹

Again, the measures show variations of radial velocities from one point to another; this enormous gaseous mass is not at rest relatively. The rings show local deformations in certain regions, indicating, in certain portions of the nebula covering very small areas, irregularities of speed which may amount to about 10 km per second. Movements of this sort are manifested in the region to the southeast of the trapezium in the direction of the star Bond 685. Moreover, there are great collective movements; with respect to the mean velocity, the northeast region is withdrawing at a speed of something like 5 km per second, while the southwest region is approaching at pretty nearly the same speed. In general, the part of the nebula which we have studied has a sort of rotary movement about the line southeast-northwest, but with numerous irregularities.

WAVE-LENGTHS OF THE LINES OF NEBULIUM

We have measured wave-lengths of the ultra-violet group, which with a reflecting telescope is, for photography, the most intense of the whole spectrum. According to Wright² this group is composed of two lines, whose wave-lengths he was able to measure on only one plate. The precise determination of the wave-lengths is important because it furnishes a sure basis for attempting the identification of these lines with those of terrestrial elements.

Since it is out of the question to separate the two lines by an absorbing filter, we measure both of them on the same plate,

¹ The velocities found up to the present are:

Keeler (1891).....	+17.7
Wright (1901).....	+16.2
Vogel (1902).....	+17.4
Frost and Adams (1904).....	+18.5

The agreement of these numbers with each other and with ours may be considered as satisfactory, especially if one remembers that the velocity is not the same for all points and that the various observations probably do not apply to the same region.

² *Astrophysical Journal*, 16, 53, 1902.

obtained with an étalon of thickness so chosen that the systems of rings of the two radiations are entirely separated. A preliminary measurement made with a difference of path of 250 microns gave a first approximation; the definite measurement was made with a difference of path of 1.3 mm.

To eliminate the effect of radial velocities in the result, the measurement was made according to the method set forth above, by determining the radii of the first five rings in the northwest direction from the trapezium. It is there that the study of radial velocities had shown the fewest inequalities of speed from point to point. The value +17.6 was adopted for the radial velocity of this region.

When the measured lines are compared with the violet radiation of mercury, which is rather far from them in the spectrum, it is necessary to make a small correction to take account of the dispersion of the change of phase by reflection from silver.¹ This correction has been determined by a study in the laboratory. For that purpose we had an étalon of small thickness constructed (130 microns) with the same silvered surfaces, and the resultant rings were measured, radiations of known wave-length being used. The difference in optical thickness in passing from λ 4358 to λ 3728 is only 0.0025 μ ; the correction of the wave-length is 0.014 A.

Reduced to the international system the wave-lengths for a source at rest with respect to the observer are:

$$\begin{array}{r} 3726.100 \\ 3728.838. \end{array}$$

The first of these two lines is the more intense.

The values we have given are exact to a hundredth of an angstrom.

The values given by Wright reduced to the international system are:

$$\begin{array}{r} 3726.25 \\ 3728.85 \text{ with an uncertainty of } \pm 0.2. \end{array}$$

In the list of the lines of known elements, none is found that can be identified with either of these two rays. Before precise measurements had been taken and before we knew that this line

¹ *Ibid.*, 28, 169, 1908.

was double, the idea had been expressed that it could be attributed to oxygen, which has a rather strong line in this region. Now the wave-length of this line of oxygen in the international system is 3727.35. It falls at about an equal distance from the two lines of the nebula and the interval between both of them and it is much too large for identification to be even contemplated.

ATOMIC WEIGHT OF NEBULIUM. TEMPERATURE OF THE NEBULA

The kinetic theory of gases establishes a correlation between the velocity of agitation of the luminous particles, and thus the width of the lines, and the atomic weight and the temperature of the luminous gas. Now the study of interference rings permits us to obtain the width of the lines by increasing the difference of path and finding to what limit the interference rings are visible. All calculations lead to the following formula: Let T be the temperature of the gas, m the atomic weight of the luminous particles, referred to the ordinary system of atomic weights ($O=16$), and N the order of interference from which point the rings cease to be visible, and we have

$$N = 1.22 \times 10^6 \sqrt{\frac{m}{T}}$$

Experiment has, in every case studied up to date, verified this formula when for m is substituted the atomic mass of the luminous gas, for the reason that the luminous particles have the same mass as the atom.¹

The experimental determination of N therefore reveals a relation between m and T . In utilizing the radiations of a known gas, we have a measurement of the temperature of the source. Inversely, if the temperature is known, one can determine the atomic weight of a gas, known to us only by its spectrum. More simply, if the source gives at the same time known and unknown lines, the temperature is eliminated, and the relations of the atomic weights is given by the square of the ratio of the limits of interference.

We looked for the limits of interference for the hydrogen and for the lines of unknown origin, in particular the double ultra-

¹ H. Buisson and Ch. Fabry, *Journal de physique* (5), 2, 442, 1908.

violet line. Étalons are used of gradually increasing thickness, until the interference rings cease to appear.

Hydrogen.—We used only the ray H_{γ} , operating by photography. Interference rings are still visible with a difference of path of 4 mm (order of interference 9200). The limit of interference is a little above this number, probably very close to 10,000.

Nebulium.—We studied by photography the double line $\lambda\lambda$ 3726–3729. To obtain the limit of interference, we worked with increasingly large thicknesses selected in such a manner that the systems of fringes given by the two lines coincide. Exact knowledge of the wave-lengths permits a simple calculation of the differences of path for which these coincidences take place, and we found that it occurred for multiples of 0.5074 mm.

The interference rings still exist for a difference of path of 5.6 mm, that is, for a number of the order of 15,000. The limit is a little higher, and probably approaches 16,500.

This result shows that the unknown gas which emits the double ultra-violet line has an atomic weight higher than that of hydrogen. The ratio of the two atomic weights is $(\frac{16,500}{10,000})^2 = 2.74$. A figure in the neighborhood of 3 is therefore the probable value of the atomic weight of this gas.

A strong green line $\lambda = 5006$ is also due to an unknown gas. We have made, thus far, only visual observations on this radiation, less exact than photographic observations. In spite of the feeble intrinsic brightness of the nebula, rings of which the order of interference reaches 11,000 were distinctly seen. The green line is therefore also emitted by a gas of greater atomic weight than hydrogen. It is not easy to obtain an exact value of the limit, but we consider as probable that this limit is less than 16,500, and, consequently, the green ray is emitted by a gas of lower atomic weight than the body which emits the ultra-violet group.

It is curious to note that the classification of elements recently given by Rydberg leads to the admission, between hydrogen and helium, of two unknown elements having respectively the atomic weights 2 and 3.

Temperature.—The limit of interference of the hydrogen line permits, by means of the formula given above, the calculation of

the temperature of the luminous gas. Assuming 10,000 for this limit, we find a temperature of 15,000 degrees. This number is a maximum; every accessory cause tending to diminish the clearness of the fringes will cause us to find a temperature that is too high, e.g., the differences in radial velocities of gaseous masses radiating to the same point.

CONCLUSIONS

It is to be hoped that further results may be obtained by following the method which we have indicated. There are in particular still to be made the more detailed study of the velocities, on a greater scale, and the study of the green line by photography. The use of absorbents to isolate a radiation is never completely satisfactory. It might be possible to separate the images produced by the various lines by means of dispersive apparatus which would give them all on a single plate. There would be opportunity further to apply the interferential method to other nebulae, in particular to the planetary nebulae.

We must emphasize the simplicity of the apparatus used and the ease with which it can be mounted on the telescope. When the silverings have been carefully selected, the interferential apparatus does not cause the loss of much light and permits the study of objects of very feeble intrinsic brightness.

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June 1914