SUGGESTIONS ON THE CLASSIFICATION OF THE VARIOUS SPECIES OF HEAVENLY BODIES.[1]

IV.

IV.—ON THE SPECTRA OF STARS OF GROUP II.

IN the previous part of this memoir I have attempted to give a general idea of that grouping of celestial bodies which in my opinion best accords with our present knowledge, and which has been based upon the assumed meteoric origin of all of them.

I now proceed to test the hypothesis further by showing how it bears the strain put upon it when, in addition to general grouping, it is used to show us how specific differences are arrived at.

I. GENERAL DISCUSSION OF DUNÉR'S OBSERVATIONS.

In the paper communicated to the Royal Society on November 17 I pointed out that the so-called "stars" of Class III.*a* were not masses of vapour like our sun, but swarms of meteorites; the spectrum being a compound one, due to the radiation of vapour in the interspaces and to the absorption of the light of the red- or white-hot meteorites by vapours volatilized out of them by the heat produced by collisions.

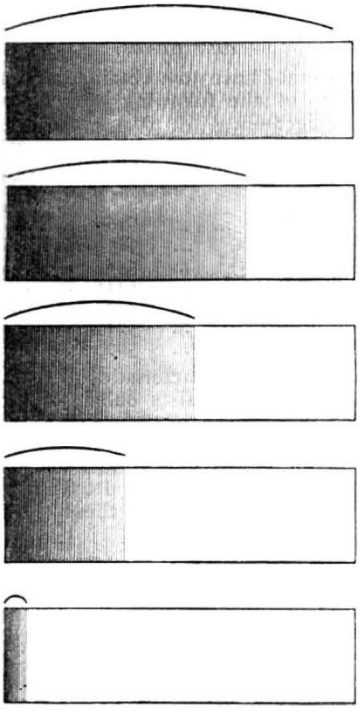

FIG. 6.—Diagram showing how an absorption fluting varies in width according to the quantity of absorbing substance present.

I also showed that the radiation was that of carbon vapour, and that some of the absorption was produced by the chief flutings of Mn and Zn.

Dunér in his map gives eleven absorption bands, chiefly flutings, in Class III *a*, but in the case of the tenth and eleventh bands there is some discrepancy between his map and the text, to which reference will be made subsequently. His measurements are of the darker portions of the flutings, speaking generally.

It will be clear at once that in the case of the *dark* flutings the dark bands should agree with the true *absorption* of the vapours, and that when the amount of absorption varies, only that wave-length away from the maximum of the flutings will vary. Thus, the same fluting may be represented as in Fig. 6, according to the quantity of the absorbing substance present.

In the case of the *bright* flutings, however, the dark bands on either side may *in some cases* be produced partly by contrast only, and the brighter and wider the bright flutings are the more they will appear to vary, and in two ways: first, they will dim by contrast when the bright fluting is dimmer than ordinary; and secondly, the one on the side towards which the bright fluting expands from its most decided edge will diminish as the bright fluting expands (see Fig. 7).

There is also another important matter to be borne in mind. As these spectra are in the main produced by the integration of the continuous spectra of the meteorites, the bright flutings of carbon, and the dark flutings produced by the absorption of the continuous spectra by the vapour surrounding each meteorite; the proportion of bright fluting area to dark fluting area will vary with the reduction of the spacing between the meteorites.

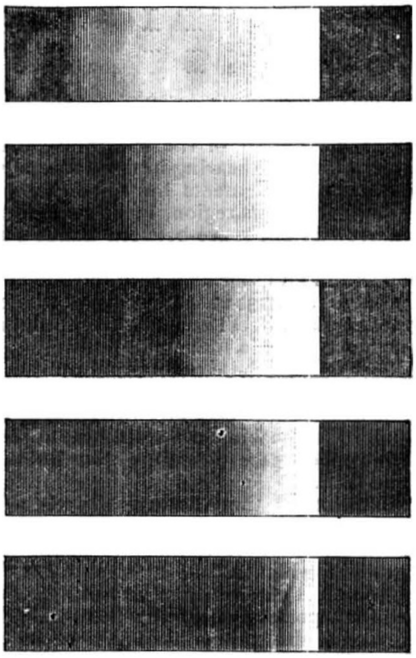

FIG. 7.—Diagram showing the variation in width of a bright fluting, and the consequent variation in width of the contrast band at the fainter edge.

If any bright or dark flutings occur in the same region of the spectra when the spaces are greatest, the radiation effect will be stronger, and the absorption fluting will be "masked;" where they are least the radiation itself will be masked. This reasoning not only applies to flutings but to lines also.

The Radiation Flutings.

We will first deal with the radiation flutings—those of carbon. The brightest less refrangible edge of the chief one is at wave-length 517, where it sharply cuts off the tail end of the absorption of the magnesium fluting the darkest edge of which begins at 520, as the carbon light from the interspace pales the absorption. The same

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[1] The Bakerian Lecture, delivered at the Royal Society on April 12, by J. Norman Lockyer, F.R.S. Continued from p. 11.

thing happens at the more refrangible edge of the other absorption of Mg at 500, as Dunér's figures show.

	Less refrangible edge.	More refrangible sharp edge.
Band 8 (absorption of Mg)	502	496 in α Herculis.
	501	496 in ρ Persei.
	503	496 in R Leonis Min.
	505	496 in β Pegasi.

If this explanation of the rigidity of the less refrangible edge may be accepted, it is suggested that the rigidity of the end of band 8 at 496, near the nebula line 495, seems to indicate that we may have that line as the bright, less refrangible, boundary of another radiation fluting.

The fluting at 517 is the chief radiation fluting of carbon. The next more refrangible one, which would be most easily seen, as the continuous spectrum would be less bright in the blue, has its less refrangible and brightest edge at 474.

This in all probability has been seen by Dunér, though, as before stated, there is here a discrepancy between his maps and his text. It lies between his dark bands 9 and 10, the measurements of which are as follow:—

	Less refrangible edge.	More refrangible edge.
Band 9	482	476 in α Orionis.
	484	477 in β Pegasi.
Band 10	472	460 in α Orionis.
	474	462 in α Herculis.

It is not necessary for me to point out the extreme and special difficulty of observations and determinations of wave-lengths in this part of the spectrum. Taking this into consideration, and bearing in mind that my observations of the chemical elements have shown me no other bands or flutings in this region, I feel justified in looking upon the narrow bright space between bands 9 and 10 as an indication of another carbon fluting—the one we should expect to find associated with the one at 517, with its bright edge at 473 instead of 476, where Dunér's measurements place it. There is a bright fluting in this position in Nova Orionis.

I shall refer to both these points later on.

The third fluting, the carbon one with its brightest edge at 564, is certainly also present; though here the proof depends upon its masking effect, and upon the manner in which this effect ceases when the other flutings narrow and become faint.

In addition to these three flutings of carbon, which we shall distinguish in what follows as carbon A, there is sometimes a fourth more refrangible one beginning at wave-length 461, which is due to some other molecular form of carbon. It extends from wave-length 461 to 451, and, as we shall presently see, it is this which gives rise to the apparent absorption band No. 10 in the blue; this we shall distinguish as carbon B.

It is very probable also that in some cases there is, in addition to carbon A and carbon B, the hydrocarbon fluting which begins at wave-length 431, the evidence of this being Dunér's apparent absorption band 11. It may be remarked here, that although most of the luminosity of this fluting is on the more refrangible side of 431, there is also a considerable amount on the less refrangible side.

With regard to bands 9, 10, and 11, then, there is little doubt that they are merely dark spaces between the bright blue flutings of carbon, and that whether they are seen or not depends upon the relative brightnesses of the carbon flutings and the continuous spectrum from the incandescent meteorites. When the continuous spectrum is faint, it will not extend far into the blue, and the resulting dark space between the bright carbon A fluting at 474 and the end of the continuous spectrum is the origin of the apparent absorption band 9. When the continuous spectrum gets very bright, band 9 should, and does, disappear. On reference to the maps of the spectra of the "stars" with bright lines, it will be seen that the broad apparent absorption band in the blue agrees exactly in position with band 9, and it undoubtedly has the same origin in both cases. This band may therefore be regarded as the connecting link between the bodies belonging to Group I. and those belonging to the group under consideration.

Band 10 is the dark space between the bright carbon A fluting at 474 and the carbon B at 461, and can only exist as long as the carbon flutings are brighter than the continuous spectrum. Dunér's mean values for the band are 461–473, and on comparing these with the wave-lengths of the carbon flutings (see Fig. 10, which will be given in the next instalment) it will be seen that the coincidence is almost perfect.

There is a little uncertainty about band 11, which Dunér was only able to measure in one star, but it very probably has its origin in the dark space between the bright carbon B fluting and the hydrocarbon fluting at 431 (see Fig. 10). This would give a band somewhat broader and more refrangible than that shown in Dunér's map; but, as already pointed out, great accuracy in this part of the spectrum cannot be expected.

Chemical Substances indicated by the Absorption Flutings and Bands.

I may state that I have now obtained evidence to show that the origin of the following *absorption* flutings is probably as under:—

No. of Fluting.	Origin.	Wave-length of darkest most refrangible edge.	Wave-length of less refrangible end, given by Dunér as measured in α Orionis.
2	Fe	616	628
3	Mn (2) ...	585	595
4	Mn (1)[1] ...	558	564
5	Pb (1)[2] ...	544	550
6	Ba[3]	524	526
7	Mg	521	517
8	Mg	500	495

These flutings are characteristic of the whole class, and Dunér's catalogue consists chiefly of a statement of their presence or absence, or their varying intensities, in the different stars.

He gives other bands and wide lines which he has measured specially in α Orionis. I have also discovered the origin of the majority of these. They are as follows:—

			Wave-length.
	I.	Fluting of Cr (1)	581
	II.	?	570–577
	III.	Fluting of Pb (2)	567
	IV.	?	543
	V.	Line of Mn seen in bunsen ...	538–540
	VI.	Band of Ba	532–534
Lines	1.	Fluting of Cr (2)...	559[4]
	2.	,, ,, (3)...	536
	3.	Line of Cr seen in bunsen	520
	4.	Ba band	514[5]
	5.	1st, 2nd, and 3rd Ba flutings ...	601
	6.		634
	7.		649

Band 1, which extends from wave-length 649·5 to 663·8, has not yet been allocated.

Tests at our Disposal.

In order to prove that my explanation of the nature of these celestial bodies is sufficient, a discussion of the individual observations of them, seeing that differences in

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[1] Means strongest fluting.

[2] The second Pb band has been seen in α Scorpii and α Orionis. Owing to an error in the map in the former paper, this fluting was ascribed to zinc.

[3] This is the second brightest band, wave-length 525. The first, at wave-length 515, is masked by the radiation fluting at 516.

[4] This is not given by Dunér. It would be masked by the Mn fluting in the star. I have inserted it to show that we could not be dealing with the 3rd fluting of Cr at 536 if we could not explain the apparent absence of the 2nd.

[5] In the early stages this band is masked by the vivid light coming from the carbon in the interspaces.

the spectra are known to exist, should show that all the differences can be accounted for in the main by differences in the amount of interspace; that is to say, by a difference between the relative areas of space and meteorite in a section of the swarm at right angles to the line of sight. I say in the main, because subsequent inquiry may indicate that we should expect to find minor differences brought about by the beginnings of condensation in large as opposed to small swarms, and also by the actual or apparent magnitudes of the swarms varying their brilliancy, thus enabling a more minute study to be made of the same stage of heat in one swarm than in another.

How minor differences may arise will be at once seen when we consider the conditions of observation.

The apparent point of light generally seen is on my view produced not by a mass of vapour of more or less regular outline and structure, but by a swarm of meteorites perhaps with more than one point of condensation.

An equal amount of light received from the body may be produced by any stage, or number of nuclei, of condensation; and with any differences of area between the more luminous centre and the outliers of the swarm.

All these conditions producing light of very different qualities are integrated in the image on the slit of the spectroscope.

I have said "generally seen," because it has been long known that many of the objects I am now discussing are variable, as well as red, and that at the minimum they are not always seen as sharp points of light[1] but have been described as hazy.

The severe nature of the tests at our disposal will be recognized when we inquire what must follow from the variation of the spacing. Thus, as the spacing is reduced—

I. The temperature must increase.

- α. Vapours produced at the lowest temperatures will be the first to appear.
- β. The spectrum of each substance must vary with the quantity of vapour produced as the temperature increases, and the new absorptions produced must be the same *and must follow in the same order* as those observed in laboratory experiments.

II. The carbon spectrum must first get more intense and then diminish afterwards as the spaces, now smaller, are occupied by vapours of other substances.

- α. The longest spectrum will be that produced by mean spacing.
- β. The masking of the dark bands by the bright ones must vary, and must be reduced as the mean spacing is reduced.

III. The continuous spectrum of the meteorites must increase.

- α. There will be a gradually-increasing dimming of the absorption-bands from this cause.
- β. This dimming will be entirely independent of the width of the band.

IV. The spectrum must gradually get richer in absorption-bands.

- α. Those produced at the lowest temperatures will be relatively widest first.
- β. Those produced at the highest temperatures will be relatively widest last.
- γ. They must all finally thin.

These necessary conditions, then, having to be fulfilled, I now proceed to discuss M. Dunér's individual observations. I shall show subsequently that there are, in all probability, other bodies besides those he has observed which really belong to this group.

II. DISCUSSION OF DUNÉR'S INDIVIDUAL OBSERVATIONS.

Consideration of the Extreme Conditions of Spacing.

Cæteris paribus, when the interspaces are largest we should have a *preponderance* of the radiation of carbon, so far as quantity goes. The bands will be wide and pale, the complete radiation will not yet be developed; a minimum of metallic absorption phenomena—that is, only the flutings of magnesium (8 and 7), the first fluting of manganese (3), and the first fluting of iron (2); but the great width of the bright band at 517 will mask band 8.

When the interspaces are least, the radiation of carbon should give place to the absorption phenomena due to the presence of those metallic vapours produced at the highest temperature at which a swarm can exist as such; the bright flutings of carbon should be diminished, and the true absorption flutings of Mg, Fe, Mn, Pb, and the band of Ba, should be enhanced in intensity.

There will be an *inversion* between the radiation and absorption.

The highest intensity of the absorption phenomena will be indicated by the strengthening of the bands 2, 3, 4, 5, and 6; and the appearance of the other flutings and bands specially recorded in α Orionis. The bands 7 and 8 will disappear as they are special to a low temperature, and will give way to the absorption of manganese, iron, *b*, &c.

This inversion, to deal with it in its broadest aspect should give us at the beginning 7 strong, and 2, 3 weak, and at the end 7 and 8 weak, and 2, 3 strong.

The first stage, representing almost a cometic condition of the swarm before condensation has begun, has been observed in Nos. 3,[1] 23, 24, 25, 36, 68, 72, 81, 118, 247, 249. There is a very large number of similar instances to be found in the observations. The above are only given as examples.

The *last* stage, before all the bands fade away entirely, has been observed in Nos. 1, 2, 26, 32, 33, 38, 40, 61, 64, 69, 71, 75, 77, 82, 96, 101, 116. As before, these are only given as instances.

It is natural that these extreme points along the line of evolution represented in the bodies under consideration should form, as I think they do, the two most contrasted distinctions recorded by Dunér—that is, recorded in the greatest number of cases.

Origin of the Discontinuous Spectrum.

I have already shown that when the meteorites are wide apart, though not at their widest, and there is no very marked condensation, the spectrum will extend farther into the blue, and therefore the flutings in the blue will be quite bright; in fact, under this condition the chief light in this part of the spectrum, almost indeed the only light, will come from the bright carbon. Under this same condition the temperature of the meteorites will not be very high, there will therefore be little continuous spectrum to be absorbed in the red and yellow. Hence we shall have discontinuity from one end of the spectrum to the other. This has also been recorded, and in fact it is the condition which gives us almost the most beautiful examples of the class (196, α Herculis, 141, 172, 229).

The *defect* of continuous light *in the blue* in this class, after condensation has commenced and the carbon flutings are beginning to disappear, arises from defect of radiation of the meteorites, and hence in all fully-developed swarms the spectrum is not seen far into the blue for the reason that the vapours round each meteorite are at a tempera-

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[1] Hind first noticed this in 1851. Quoted by Arago, "Astronomie Populaire."

[1] The references are to the numbers of the stars in Dunér's catalogue.

ture such that fluting absorption mainly takes place, although of course there must be some continuous absorption in the blue. This is perhaps the most highly-developed normal spectrum-giving condition; 44, 45, 55, 60, 65, 86, 92, 278 are examples.

The Paling of the Flutings.

Subsequently, the spectra are in all cases far from being discontinuous, and the flutings, instead of being black, are pale. Thus, while the bands are dark in the stars we have named, they are not so dark in α Orionis. Here, in short, we have a great distinction between this star and α Herculis, ο Ceti, R Lyræ, and ρ Persei.

Obviously this arises from the fact that the average distances between the meteorites have been reduced; their temperature being thereby increased as more collisions are possible, the vapours are nearly as brilliant as the meteorites, and radiation from the interspaces cloaks the evidences of absorption. Nor is this all: as the meteorites are nearer together, the area producing the bright flutings of the carbon is relatively reduced, and the bands 10 and 9 will fade for lack of contrast, while 8 and 7 will fade owing to the increased temperature of the system generally carrying the magnesium absorption into the line stage; *b* is now predominant (see 102, 157, 163, 114, 125, 135).

Under these conditions the *outer* absorbing metallic atmosphere round each meteorite will in all probability consist of Mn and Fe vapours, and in this position the masking effect will least apply to them. This is so (114, 116); they remain dark, while the others are pale.

Here we have the indication of one of the penultimate stages already referred to.

Phenomena of Condensation.

Dealing specially with the question of condensation,—I have already referred to possibly the first condition of all, recorded by Dunér in the observations now discussed—I may say that the first real and obvious approach to it perhaps is observed when all, or nearly all, except 9 and 10 of the flutings are *wide* and *dark*. The reasons will be obvious from what has been previously stated. Still more condensation will give all, or nearly all, the bands wide and pale, while the final stage of condensation of the swarm will be reached when all the bands fade and give place to lines. We have then reached Class II. (107, 139, 168, 264); 2 and 3 should be and are perhaps the last to go (203).

The Bands 9 and 10.

With regard specially to the bands 9 and 10, which include between them a bright space which I contend is the second fluting of carbon, I may add that if this view is sound, the absence of 10 should mean a broad carbon band, and this is the condition of non-condensation, though not the initial condition. The red flutings should therefore be well marked—whether broad or not does not matter; but they should be dark and not *pale*. Similarly the absence of band 9 means non-condensation.

Therefore 9 and 10 should vary together, and as a matter of fact we find that their complete absence from the spectrum, while the metallic absorption is strong, is a very common condition (1, 2, 6, 16, 26, 32, 39, 40, 46, 54, 60).

That this explanation is probably the true one is shown by further consideration of what should happen to the red flutings when 9 and 10 are present. As the strong red flutings indicate condensation, according to my view this condensation (see *ante*) should pale the other flutings. This happens (3, 8, 13, 28, 35, 45, 30; and last, not least, among the examples, I give 50, α Orionis).

III. RESULTS OF THE DISCUSSION.

The Line of Evolution.

I have gone over all the individual observations recorded by Dunér, and, dealing with them all to the best of my ability in the light afforded by the allocation of the bands to the various chemical substances, the history of the swarms he has observed seems to be as follows:—

(1) The swarm has arrived at the stage at which, owing to the gradual nearing of the meteorites, the hydrogen lines, which appeared at first in consequence of the great tenuity of the gases in the interspaces, give way to carbon. At first the fluting at 473 appears (as in many bright-line stars), and afterwards the one at 517. This is very nearly, but, as I shall show subsequently, not quite, the real beginning of Class III.*a*, and the radiation is now accompanied by the fluting absorption of Mg, Fe, and Mn—bands 7, 2, 3. This is the absorption produced at the temperature of the oxy-coal gas flame, while the stars above referred to give us the bright line of Mn seen at the temperature of the bunsen.

(2) The bright band of carbon at 517 narrows and unveils the Mg absorption at band 8. We have 8 now as well as 7 (both representing Mg), added to the bands 2 and 3, representing Fe and Mn, and these latter now intensify.

(3) The spacing gets smaller; the carbon, though reduced in relative quantity, gets more intense. The second band at 473 in the blue gets brighter as well as the one at 517. We have now bands 9 and 10 added. This reduced spacing increases the number of collisions, so that Pb and Ba are added to Mg, Fe, and Mn. We have the bands 2, 3, 4, 5, 6, 7, 8, 9, and 10. This is the condition which gives, so to speak, the normal spectrum.

(4) This increased action will give us a bright atmosphere round each meteorite, only the light of the meteorite in the line of sight will be absorbed: we shall now have much continuous spectrum from the interspaces as well as the vapour of carbon. *The absorption flutings will pale*, and the Mg flutings will disappear on account of the higher temperature, while new ones will make their appearance.

(5) Greater nearness still will be followed by the further dimming of the bright carbon flutings including the one at 517. The blue end of the spectrum will shorten as the bands fade, narrow, and increase in number. If the star be bright, it will now put on the appearance of α Orionis; if dim, only the flutings of Fe and Mn(1), bands 2 and 3, will remain prominent.

(6) All the flutings and bands gradually thin, fade, and disappear. A star of the third group is the result.

In the latter higher-temperature stages we must expect hydrogen to be present, but it need not necessarily be visible, as the bright lines from the interspaces may cancel or mask the absorption in the line of sight of the light of the meteorites; but in case of any violent action, such as that produced by another swarm moving with great velocity, we must expect to see them bright, and they are shown bright in a magnificent photograph of ο Ceti, taken for the Draper Memorial, which I owe to the kindness of Prof. Pickering. I shall return to this question.

Stages antecedent to those recorded by Dunér.

So far I have referred to the swarms observed by Dunér. The result of the discussion has been to show that all the phenomena are included in the hypothesis that the final stages we have considered are antecedent to the formation of stars of Group III., bodies which give an almost exclusively line absorption, though these bodies are probably not yet stars, if we use the term star to express complete volatilization, similar to that observed in the case of our sun.

The question then arises, Are all the mixed fluting stages really included among the objects already considered?

It will be remembered that in my former communication I adduced evidence to the effect that the mixed fluting stage was preceded by others in which the swarms were still more dispersed, and at a lower temperature. The first condition gives us bright hydrogen; the last little continuous spectrum to be absorbed, so that the spectrum is one with more bright lines than indications of absorption; and, in fact, the chief difference between the spectra of these swarms and of those still sparser ones which we call nebulæ lies in the fact that there are a few more bright metallic lines or remnants of flutings; those of magnesium, in the one case, being replaced by others of manganese and iron.

If my view be correct—if there are stages preceding those recorded by Dunér in which we get both dark and bright flutings—it is among bodies with spectra very similar to these that they should be found.

The first stage exhibited in the objects observed by Dunér is marked by flutings 7, 3, and 2 (omitting the less refrangible one not yet allocated), representing the flutings Mg, Mn, and Fe visible at the lowest temperatures.

The stars which I look upon as representing a prior stage should have recorded in their spectra the flutings 7 and 3 (without 2), representing Mg and Mn.

(*To be continued.*)

THREE DAYS ON THE SUMMIT OF MONT BLANC.

ALPINE men are already beginning to think of the work of the coming season. We commend to their attention the following notes relating to the experiences of M. Richard, who spent three days during the past summer on the summit of Mont Blanc, with a view to making a series of continuous meteorological and other observations. There are many Alpine men who might, if they pleased, follow his example without much inconvenience to themselves and with considerable advantage to science. The following is a summary of the record which M. Richard has contributed to *La Nature*:—

The summit of Mont Blanc is a station of the utmost importance to meteorology, since it rises to a great height (4810 metres), and overtops the whole Alpine group. But it had not hitherto been considered possible to remain there for any length of time. De Saussure, whose statue is erected at Chamounix, passed some days in 1788, on the Géant hill, at the height of 3510 metres. In 1844, Martins, Bravais, and Le Pileur, pitched their tent at the Grand-Plateau, 4000 metres high, and here they passed several days, and made numerous and important observations. Hitherto no explorer had remained on the summit of the mountain itself for any length of time; tourists making but a very short stay—usually only a few minutes From these facts we can see the importance of the scientific expedition carried out in the summer of 1887, with great success, by M. Joseph Vallot, one of the most daring and able members of the Alpine Club. Having made, in 1886, a series of physiological observations, during the ascent of some of the highest peaks of the Alps, he determined to establish on Mont Blanc three temporary meteorological observatories, the first at Chamounix, 1050 metres high, the second on the rocks of the Grands-Mulets, 3059 metres high, and the third on the summit of Mont Blanc. He constructed meteorological sheds, and furnished each of them with registering instruments constructed by MM. Richard Brothers—a barometer, a thermometer, and a hygrometer. The instruments placed at Chamounix and the Grands-Mulets were inspected every week, but those at the summit could not be reached for fifteen days, on account of bad weather. To superintend the lower stations he procured the assistance of M. Henri Vallot, a distinguished engineer, on whose competence and carefulness he could rely. At Chamounix, M. Joseph Vallot's plan was considered impracticable. He executed it, however, in company with M. F. M. Richard, one of the makers of the registers. No less than twenty-four guides were necessary, on account of the great weight of the baggage (250 kilogrammes). At midday, July 27, 1887, they began the ascent to the Grands-Mulets. On account of the late start, the party, overtaken by night, arrived at the Grands-Mulets at 10 o'clock. Getting to bed at 11 o'clock, the travellers set out again the next morning at 3, after a light meal.

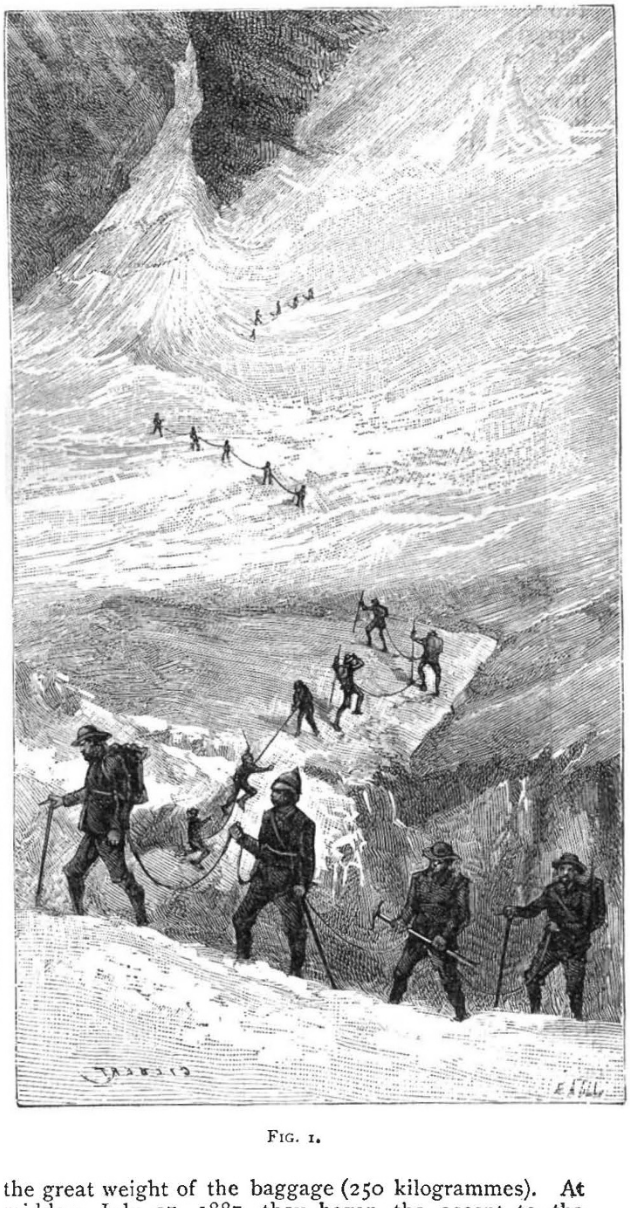

Fig. 1.

M. Richard then proceeds to tell the story of the journey and of the time spent on the top of Mont Blanc. The ascent from the Grands-Mulets is difficult, but not very dangerous when the snow is good. Crevasses have