

ART. XIII.—*Remarks on the Luminosity of Meteors as affected by Latent Heat*; by BENJAMIN V. MARSH.

IN the January number of this Journal, in the notice of Mr. Quetelet's work, "*Sur la Physique du Globe*," objection is made to certain "novel ideas on the constitution of the atmosphere,"—apparently adopted by the author mainly for the purpose of explaining the fact that shooting stars and meteorites always disappear before reaching the earth. The notice says, "we observe these meteors at elevations of 140 to 160 miles; they increase in brightness as they approach the earth; they disappear entirely as they approach the lower part of the atmosphere, as if they entered a medium which had not the elements necessary for their continued brilliancy."

The aim of the present paper is to show that the well-established fact thus stated may be fully and satisfactorily explained by other means.

Mr. Birks, in his chapter on the "*Igneous condition of matter*," says,¹ "There will thus, according to the present theory of the laws of matter, be more truth than has latterly been recognized in the old arrangement of the four elements, which placed a fourth region of fire above the solid, liquid, and gaseous constituents of our globe. In fact, above the region where the air, though greatly rarefied, is still elastic, there must be a still higher stratum where elasticity has wholly ceased, and where the particles of matter, being very widely separated, condense around them the largest amount of ether. All sensible heat, in the collision or oscillation of neighboring atoms of matter, will thus have disappeared; but latent heat, in the quantity of condensed ether or repulsive force ready to be developed on the renewed approach of the atoms, will have reached its maximum, and may be capable of producing the most splendid igneous phenomena, like the northern lights, or tropical thunder storms."

On reading the above, I was so struck with its peculiar adaptation to the explanation of meteoric phenomena, that I was induced to inquire, without any regard to the theoretical views of the author—what, according to the accepted laws of heat, must be the condition of the upper regions of the atmosphere in reference to latent heat?

"If a unit of weight of any gas, allowed to expand freely without change of pressure, is heated from the freezing point one degree, the amount of heat thus absorbed, measured in fractions of the unit, is called 'the specific heat under constant pressure.' If the same gas is heated one degree when so confined

¹ On Matter and Ether, or The Secret Laws of Physical Change; by Thomas Rawson Birks, M.A. Cambridge (England), 1862.

that its volume can not be increased, the amount of heat required to produce the change of temperature is called 'the specific heat under a constant volume.'—*Silliman's Physics*, p. 459.

The specific heat of air under constant pressure (that of water being unity) has been found to be 0.2377; specific heat of air under constant volume has been found to be 0.1678; difference 0.0699.

"Comparing these results in the case of air, we see that, when air is heated in a situation where it is free to expand, only about $\frac{1}{4}$ of the heat applied is expended in producing elevation of temperature—as in heating a room—while about $\frac{3}{4}$ of the heat is expended in producing expansion of the air, to be given out again as the room cools."—*Silliman's Physics*, p. 451.

Again: "It is a perfectly well known fact that a certain amount of heat is rendered latent in producing the expansion of a given mass of gas, and that, on condensing the gas to its original volume, the same amount of heat is set free."—*Cooke's Chemical Physics*, p. 480.

The absorption of a certain amount of heat, and the rendering of it latent, appears to be admitted as a necessary accompaniment of the act of expansion, as such, and essential to its accomplishment—whether the expansion be produced by the removal of pressure,² or by the application of heat, or by both combined. The amount absorbed must therefore depend solely upon the extent of the expansion—and air of any given density must always contain the same amount of latent heat, no matter what may be its past history or its present condition as to temperature or pressure.

Now it has been ascertained by Regnault and others, that when air is heated in a situation where it is free to expand without change of pressure, equal additions of heat make equal additions of volume—and that this holds good at all temperatures and at all pressures—also that the rate of expansion is such that air at the freezing point expands $\frac{1}{273}$ part of its bulk for every added degree of heat on Fahrenheit's scale. That is

491	cubic inches of air at 32°	become		
492	" " " "	33	"	
493	" " " "	34	"	&c.

² A striking instance of the effect of the removal of pressure is afforded on a vast scale at the fountain of Hiero, at the mines of Chemnitz in Hungary. "A part of the machinery for working these mines is a perpendicular column of water 260 feet high, which presses on a quantity of air enclosed in a tight reservoir. The air is consequently condensed to an enormous degree by this height of water, which is equal to 8 or 9 atmospheres; and when a pipe communicating with the reservoir of condensed air is suddenly opened, it rushes out with extreme velocity, instantly expands, and in so doing absorbs so much caloric as to precipitate the moisture it contains in a shower of very white compact snow, or rather hail, which may be readily gathered in a hat held in the blast."—*Silliman's Chemistry*, 1830, vol. i, p. 121.

Whence it appears that

1 vol. of air at 32°, by having its temperature raised 491° becomes 2 vols.
1 " " " " " " " 982 " 3 "
1 " " " " " " " 1473 " 4 "

&c.,—the increase being 1 volume for each 491°.

But it has already been shown that, of the heat employed in this process, about $\frac{2}{7}$ (more exactly $\frac{699}{2377}$) is absorbed by the air and rendered latent. Hence, of each 491° expended as above, $\frac{699}{2377}$, or about 144°, are rendered latent. It therefore follows that

Vol. of air.						Latent heat.
1	at 32°	by having its temp. raised 491°	becomes 2 vols. and contains	144°		
1	"	"	"	982	" 3 "	288
1	"	"	"	1478	" 4 "	432

and so on indefinitely.

Now, inasmuch as it is known that at the height of 3.43 miles the volume of a given weight of air is twice what it is at the earth's surface, and that as we ascend the number of volumes is doubled for each addition of 3.43 miles to the height, the above considerations enable us to calculate the amount of latent heat in any given weight or bulk of air at any given height within the limits of the atmosphere.

Height in miles.	Number of volumes corresponding to 1 volume at the surface of the earth.	Number of degrees of latent heat.	Latent heat in 1 volume to nearest degree.	Number of grains of air in cylinder 1 mile long and 1 foot in diameter.
<i>n</i> being—number terms of this series. <i>a</i> being—3.43.				Weight at surface of the earth—2342847 grains—334.69 poundsavoirdupois.
<i>na.</i>	2 ⁿ .	144 (2 ⁿ - 1).	144 $\left(\frac{2^n - 1}{2}\right)$	
3.43	2	144	72	1171424
6.86	4	432	108	585712
10.29	8	1008	126	292856
13.72	16	2160	135	146428
17.15	32	4464	139	73214
20.58	64	9072	142	36607
24.01	128	18288	143	18303
27.44	256	36720	143	9152
30.87	512	73584	144	4576
34.30	1024	147812	144	2288
37.73	2048	294768	144	1144
41.16	4096	589680	144	572
44.59	8192	1179604	144	286
48.02	16384	2359152	144	143
51.45	32768	4718448	144	72
54.88	65536	9437040	144	36
58.31	131072	18874224	144	18
61.74	262144	37748592	144	9
65.17	524288	75497328	144	4
68.60	1048576	150994800	144	2
102.90	1073741824	154618822512	144	$\frac{1}{2}$
137.20	1099511627776	158329674399600	144	$\frac{1}{2^2}$
171.50	1125809906842624	162129586585337712	144	$\frac{1}{2^3}$
205.80	1152921504806846976	16602069668885964400	144	$\frac{1}{2^4}$

The above table shows results thus obtained, together with some other facts bearing upon the subject.

The most important as well as the most striking fact shown by this table, is that the quantity of latent heat in a given bulk of air is sensibly constant for all heights exceeding 30 miles. Below that point it decreases rapidly as we descend, being at $3\frac{1}{2}$ miles only one-half of what it is at 30 miles.

For convenience of illustration, let us assume as our unit of measure a cylinder 1 mile long and 1 foot in diameter—this being the space traversed by a globular meteor 1 foot in diameter in going 1 mile. Such a cylinder will contain, at the surface of the earth, 335 pounds (2342847 grains) of air.

At the height of 3.43 miles it will contain 167 pounds, which, when condensed to the density of air at the surface, will evolve enough heat to raise the temperature of the original weight—say 335 pounds— 72° .

At 34.30 miles it will contain $\frac{1}{8}$ pound of air, which, condensed as before, will evolve heat sufficient to raise 335 pounds 144° .

At 68.60 miles—the weight of air is only 2 grains but its condensation will raise 335 pounds 144° —and *generally, the same bulk of air is capable of effecting the same result at any greater height, even to the extreme limits of the atmosphere.*

Now let us suppose a meteoric stone one foot in diameter (weighing say two hundred pounds) to enter the atmosphere with a velocity of ten miles per second.

In every mile that it travels, it meets with and condenses before it a bulk of air equal to our assumed unit of measure, which, compressed to the density of air at the surface of the earth, will give out heat enough to raise 335 pounds of air 144° . In one second it passes through ten units, and the heat evolved will raise 335 pounds 1440° , or the weight of the stone—two hundred pounds— 2412° , being more than sufficient to bring the whole mass to an incandescent state.

But this heat is developed, *not* in the stone weighing 200 lbs., but in a body of air, the total weight of which is at most only a few grains. The intensity of the heat in this small mass must therefore be proportionally greater. The table shows that at the height of only 55 miles the heat is sufficient to raise the temperature of the whole mass of air encountered, more than nine million degrees; and at greater heights the intensity will increase in a geometric ratio, so that at 137 miles only it becomes one hundred and fifty-eight millions of millions.

It thus appears that we have the means of accounting for a brilliancy of any imaginable intensity—*the greatest splendor being, not in the meteor, but in the air which surrounds it.*

Those particles of air which are in *immediate contact* with the stone (and those only) will of course part with a considerable

portion of their heat, which, as time is not afforded for it to penetrate the mass, must be expended in burning off or vaporizing the surface layer of the stone. The greatest elevation of temperature must evidently take place in the remaining portions of the air, which, retaining nearly the whole of the heat developed in them, will reach a state of the most brilliant incandescence, the splendor of which will be vastly increased by the presence of the stony particles thrown off from the meteor.

For convenience I have assumed that the air is in all cases compressed to the density of that at the surface of the earth. Whilst this is doubtless sufficiently correct for the purpose of illustrating the nature of the phenomena, it can of course lay no claim to accuracy. The density attained must vary with the height, velocity, &c. Again, the sudden elevation of temperature must generate an enormous elasticity which will tend to drive the incandescent particles outward from the axis of the meteor's path and thus limit the degree of condensation.

In this way the most intensely brilliant particles must be directly in front of the meteor, streaming outward in all directions. As these are left behind by the meteor in its flight they must form a cylinder of fire; but the expansion which immediately ensues, promptly cools it off, and as this cooling process must begin at the surface of the cylinder and can only reach the axis at some distance in the rear of the meteor, it will evidently convert the cylinder into a luminous cone moving base-foremost—far the greatest brilliancy being in the base itself. This is precisely the form actually observed in the great daylight meteors of 1859 and 1860 and in some others of the same class.

The conclusion to which these considerations lead, is that the upper regions of the atmosphere, even to its utmost limit, are grand reservoirs of latent heat³ most admirably adapted for the

³ Sir John Herschell in his "*Outlines of Astronomy*," p. 617, says, "The heat which they possess when fallen, the igneous phenomena which accompany them, their explosion on arriving within the denser regions of our atmosphere, &c., are all sufficiently accounted for on physical principles, by the condensation of the air before them in consequence of their enormous velocity, and by the relations of air in a highly attenuated state to heat," and he refers to the *Edinburgh Review*, Jan., 1848, p. 195. The passage in the Review is as follows:

"Arriving with planetary velocity at the confines of our atmosphere, where the air is many thousand, perhaps million times rarer than at the surface of the earth, such a body would carry before it the air on which it immediately impinged, compressing it to an enormous relative extent against its own surface, before the absolute compression could reach such a point as to determine its lateral escape. Now it has been shown by Poisson (*Ann. de Chim.*, xxiii, 341) that the latent heat of a given weight of air is greater, the lower the pressure under which it exists. A given quantity (by weight) of air, therefore, at those elevations contains more latent heat than the same quantity at the earth's surface. When condensed, therefore, it will give out more heat than would be elicited by the same extent of relative condensation from air of ordinary density, which we know to be capable of producing ignition, even under very moderate degrees of sudden compression. A source of sudden and transient heat of almost any conceivable intensity, is thus provided in immediate contact with the surface of the stone, which it would fuse and partially

protection of the earth from collision with bodies approaching it with planetary velocity from without. The intruder is instantly surrounded with a fiery envelope heated to the greatest conceivable intensity, its surface is burned off or dissipated into vapor, the sudden expansion of the stratum immediately beneath the burning surface tears the body into fragments, each of which, retaining its planetary velocity, is instantly surrounded by a similar envelope, which produces like effects; and so on, until in most cases the whole is burnt up or vaporized.

Of the vast number of meteors seen, and which may fairly be presumed to embrace great variety of material, but very few are known to reach the earth, and these few are invariably found to be composed of the most incombustible substances—flinty stones or masses of iron. Such bodies may penetrate the whole depth of the atmosphere with only a partial loss of substance, whilst those of a more combustible nature may be totally destroyed during the flight of a few miles.

vaporize, while the sudden and violent expansion of the parts immediately beneath the fused film must necessarily cause decrepitation and disruption of fragments. In short, there is no part of the phenomenon which this explanation does not reach. Mere friction against the atmosphere, as suggested by Poisson, seems quite insufficient to produce incandescence."

Although no numerical results are here given, it might be supposed that this article anticipates those given above, but such does not appear to be the fact.

The conclusion to which the mathematical investigations of Poisson led him are thus announced (*Ann. de Chim.*, 1825, xxiii, 341). "Whence we conclude in general,

$$c = (0.2689) \left(\frac{P}{p} \right)^{1-\frac{1}{k}}$$

and the value of c' can be deduced from that of c by dividing it by k . As this quantity k is greater than unity, we see that the *specific heat* of a gramme of air, and generally of any gas whatever, will increase when the elastic force, p , becomes less."

In the above, c represents the specific heat under constant pressure.

c' " " " " volume.
 $\frac{p}{P}$ " the pressure.
 " " " with barometer at 29.92 in.

and $k = \frac{c}{c'}$ and assumed = 1.3750.

Poisson treats only of "specific heat," and makes no mention of "latent heat" in any part of the article ('*Sur la Chaleur des gaz et des vapeurs.*')

But even overlooking this misquotation, and assuming, as the writer seems to have done, that, for the object in view, "specific heat" and "latent heat" might be treated as convertible terms, the ratio of increase with the increase of height is altogether too trifling to serve as the basis of any explanation of the phenomena in question. At the height of 41 miles, the specific heat, according to this formula, would be only ten times that at the surface of the earth; whereas the latent heat at that height as above stated is 589680 degrees.

But, furthermore, Poisson's result was a mere theoretical deduction, which has been proved to be altogether erroneous by the experiments of Regnault, who has shown that the *specific heat is the same for all pressures*; so that the explanation as it stands in the Review appears to be entirely without foundation.

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If, as above maintained, the observed splendor is not due to the temperature of the meteoric bodies themselves, but to that of mere envelopes of air, brought to the most intense degree of incandescence by the development of their latent heat, it is evident, that, inasmuch as this heat is nearly constant for all considerable heights, the most splendid results must be developed in the rarest portions of the atmosphere, because there the mass of the air to be acted upon by this fixed amount of heat is least; and that as we descend, a point may be reached where the mass is so great that the intensity will fall short of that required to produce incandescence, and all luminosity must instantly cease. The meteor will then have "entered a medium which has not the elements necessary to its continued brilliancy."

The table shows that at the height of $10\frac{1}{2}$ miles, with the assumed degree of condensation, the intensity will not exceed one thousand degrees, even without making any allowance for the portion of heat which must always be absorbed by the meteor itself. Luminosity must therefore cease above this limit, and the meteor must perform the remainder of its journey to the earth as a dark body, unless the velocity be such as to produce a much greater condensation. The daylight meteor of November 15, 1859, owing to its amazing velocity, passed this limit, disappearing at the height of only six or eight miles without any perceptible diminution of velocity, but this is believed to be a rare instance.

Whilst the luminous track of those meteors which have their paths directed downward is always cut short before reaching the earth, there are instances of very extended flights, in meteors moving more nearly horizontally. That of July 20th, 1860, was seen to traverse the atmosphere more than a thousand miles, and finally disappeared in the distance over the Atlantic apparently without having become extinct. But this meteor had at no time an elevation less than forty miles, and therefore did not leave the medium which favored its continued brilliancy.

The preceding views may be thought to imply that all meteors should be seen the instant they enter the atmosphere, and consequently at a uniform elevation. But it must be remembered that the extremely cold surface of the meteor (having the temperature of interplanetary space, say 100° below zero) must first be heated; and the distance passed through before this is accomplished must depend upon the size and conducting power, but more especially upon the velocity of the body, and the results may therefore differ widely.

A meteoric body of great conducting power and very moderate velocity might upon first entering the atmosphere absorb so large a portion of the whole heat developed, as to prevent the development of any luminosity until a very considerable depth

of air had been traversed. On the other hand, we have in the great daylight meteor of 1859 an example of the effects of the most extreme velocity—probably between fifty and a hundred miles per second. This body became visible at a probable height of near two hundred miles, and exhibited a brilliancy almost if not quite equal to that of the sun, being a conspicuous object to persons who were more than two hundred miles from the nearest point in its path, and maintained its luminosity until within a few miles of the earth.

Philadelphia, May 23, 1863.