Mountains, Rain, and Snow. By R. C. Nichols, F.S.A.

THE effect of mountains in inducing rainfall has long been a familiar circumstance. The air of the plains, more or less charged with vapour, is driven upwards as it encounters the mountains, it undergoes expansion, and is thereby chilled so that it can no longer support the same quantity of vapour, which is accordingly precipitated in showers of rain, or, if the refrigeration is sufficient, in snow. It is generally believed that the cold of the mountains aids in the work of condensation.*

But the question is here suggested, why are the mountains cold? The amount of sunshine received by them is as great as that on the plains—greater indeed, as it comes to them unsifted by the aqueous vapour of the lower regions of the atmosphere, which absorbs a large portion of the heat rays before they reach the earth. On the other hand, their heat is more freely radiated into space for want of this very covering. A sufficient explanation of the mountain cold may be afforded by the refrigeration of the air which is forced up their flanks by the winds. But if we call in the coldness of the air to account for that of the mountains, we must not attribute to them generally a similar action upon the air, though it is, of course, not only probable, but also consonant with experience, that the normal relation, whichever it may be, may occasionally be reversed.

Some light may be thrown upon this and some other questions by attempting to estimate approximately, by the aid of figures, the actual results which will follow from given circumstances. Let us suppose a current of air, at a temperature of 70° Fahrenheit, flowing over the plains or low hills at the base of a mountain chain, at an elevation of about 400 feet above the sea, the pressure being 14·25 lbs. on the square inch, corresponding to a height of the barometer of 29·5 in. at the sea level. We will further suppose this air to be carried up the face of the mountains to an elevation of somewhat more than 11,000 ft., where the pressure is only 9·5 lbs. per inch. It will be expanded in the inverse ratio of these pressures, or rather this would be the ratio but for the effect of refrigeration, and the refrigeration produced may be measured by the amount of energy expended in the expansion.† This would be, if the

* See Tyndall, 'The Forms of Water,' &c., § 8, p. 27.

† This follows necessarily from the principle demonstrated by Dr. Joule that the refrigeration results entirely from the performance of mechanical work in the act of expansion. If the expansion takes place

temperature remained the same, for every cubic foot of the original volume of the air, an amount of force which would be

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into a vacuum, there is no reduction of temperature. The following indications will suffice to show the manner in which the figures given in these pages have been obtained. If p_1 be the original pressure per square foot, p_2 the pressure after expansion, U_1 the work of expansion per cubic foot of original volume in foot-pounds, assuming the temperature to remain uniform, then :

$$U_1 = p_1 \,(\text{h. l. } p_1 - \text{h. l. } p_2).$$

And the work of contraction consequent on the reduction of temperature from t_1 to t_2 may be taken at :

$$U_2 = p_1 \frac{t_1 - t_2}{459 + t_1}\left(1 + \frac{\text{h. l. } p_1 - \text{h. l. } p_2}{2}\right)$$
$$= \frac{t_1 - t_2}{459 + t_1}\left(p_1 + \frac{U_1}{2}\right),$$

which is slightly in excess of the true value.

So long as no condensation of vapour occurs, the true value of $U_2 - U_2$, that is to say, of the work of expansion, taking into account the effect of temperature, is :

$$U = \frac{1 - \left(\frac{p_2}{p_1}\right)^{\frac{n\,p_1}{1 + n\,p_1}}}{n}$$

where $\frac{1}{n} = (459 + t_1)u$; u being the equivalent in work estimated in foot-pounds of the heat consumed in raising the temperature of one cubic foot of the air one degree. Or, if p_2 be the pressure at which the temperature will be reduced to $t_2°$,

$$\log.\, p_2 = \log.\, p_1 - \frac{1 + n\,p_1}{n\,p_1} \log. \frac{459 + t_1}{459 + t_2}$$

$$\text{and } \log.\, \overline{459 + t_2} = \log.\, \overline{459 + t_1} - \frac{n\,p_1}{1 + n\,p_1} (\log.\, p_1 - \log.\, p_2).$$

But these two equations are not available when the problem is further complicated by the condensation of a portion of the vapour, and the error which arises from first taking the value of U_1, and afterwards that of U_2, as before given, is not important.

The amount of aqueous vapour which can be held in suspension at a given temperature is calculated from Mayer's formula. The latent heat of aqueous vapour at the temperature $t°$, is taken at 1091·7 — ·695 $(t - 32)$, that of water at 32° (above ice of the same temperature) at 142·56, the specific heat of air by weight, the pressure being constant, at 0·2377, and that of aqueous vapour at 0·837, these last *data* being all on the authority of Regnault.

The specific heat of air and vapour, at constant volume (that is, irrespective of expansion or contraction), has been calculated on the principle that the mechanical work indicated by the specific heat at constant pressure, must be equal to the work indicated by that at consufficient to raise 832 lbs. weight to the height of one foot, or in other words 832 foot-pounds. This amount of force converted into heat would raise the temperature of 1·08 lbs. of water one degree, and to obtain this amount of force the temperature of 1 lb. of water would have to be lowered 1°·08. Or to obtain it by the refrigeration of one cubic foot of air which, at the assumed temperature of 70° and pressure of 14·25 lbs., would weigh 509 grs., this air must be lowered 88°. But the reduction of temperature also occasions contraction, or diminishes the expansion of the air, and, allowing for this, the actual reduction of temperature would be about 59°, or to 21° below the freezing point. If the same air were carried further to a height of about 13,250 ft., where the pressure was only 9·15 lbs, the temperature would fall to zero.

But we have not yet taken into account the effect of the aqueous vapour contained in the air. It is the force developed, or heat set free, in the condensation of a portion of this vapour, which prevents the ordinary summer temperature in the higher regions of the Alps from falling to or below the zero of Fahrenheit, as the results just obtained might lead us to expect.

Suppose the air to have been originally saturated with moisture, or to have contained 7·75 grs. of vapour to the cubic foot. At 32° only 2·12 grs. will remain in the state of vapour per cubic foot. But at 9·5 lbs. pressure, and at 32°, one cubic foot of air will have been expanded to 1·39 cubic ft., and 2·95 grs. out of the original 7·75 will remain uncondensed. The amount of energy obtained by the condensation of 4·8 grs. will be 571 foot-pounds, and by the diminished expansion of the air consequent on the reduction of the temperature 174 foot-pounds. The weight of the cubic foot of air, exclusive of vapour, would be 497 grs., and its reduction and that of the remaining vapour to 32°, would give 358 foot-pounds. The sum of these numbers is 1,103 foot-pounds, whereas the work of expansion amounts only to 832, showing that the temperature will not fall so low. The actual reduction will be only to 41°, and 4·17 grs. of vapour will remain uncondensed.* This pressure and temperature indicate a height of about

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stant volume, plus the work of expansion, $p\,(V_2 - V_1)$. The values thus obtained are for air ·1685, and for aqueous vapour ·726.

* At 41°·8 the work of condensation will amount to 424 foot-pounds.

,,	,,	diminished expansion ,,	132	,,
,,	,,	reduction of temperature ,,	276	,,
		Total . .	832 foot-pounds.	

11,550 ft. To obtain a reduction to 32°, the air must be elevated to a height of about 14,500 ft.

But suppose the original amount of moisture in the air not to have exceeded 2·59 grs. to the cubic foot. The reduction of the air and vapour to 32° will give 363 foot-pounds, and the expansion of the air until the pressure is reduced to 11·05 lbs., corresponding to an elevation of nearly 7,400 ft., will require 526 foot-pounds less 163 due to diminished expansion, or 363 foot-pounds; a cubic foot of air will be expanded to 1·22 cubic feet, and 2·59 gr. of vapour will remain uncondensed, so that the air at this height will be reduced to the freezing point without the condensation of any part of the vapour.* A further reduction of pressure to 9·5 lbs., corresponding to a height of about 11,300 ft., would cause a reduction of temperature to 18°·5, and the condensation of ·87 gr. of vapour to the state of snow, leaving 1·72 gr. uncondensed. If no more than ·8 gr. of vapour per cubic foot had been contained in the air, the temperature would fall to 32° below 7,600 ft., and to zero at about 13,250 ft., without any condensation taking place.

We may conclude, then, that the temperature of the air about the mountain summits would be not much above zero on a clear day, when the temperature on the plains is 70°, if it were not for the direct action of the sun's rays, and for radiation from the ground, both during and after its elevation. Now, there are reasons for believing that the temperature of the mountains themselves a little below the surface of the ground will not vary much from 32°. The surface is frequently heated by the sun, which melts a portion of the snow, causing the water derived from it to percolate the rocks. If this freezes again it must in so doing give up its latent heat, which will suffice to raise a large amount of snow or rock to the same temperature. When, therefore, the air which rises from the plains is comparatively dry, the mountains will generally be warmer than the air, and will supply vapour to it if it is capable of taking up an additional quantity.

These are the circumstances under which the so-called 'cloud-streamers' are formed at the tops of lofty peaks, under a clear sky. The snow or ice upon the peak is melted and evaporated by the rays of the sun, and the vapour rising into the colder air is condensed into cloud, which is drifted away by

* A direct calculation of the pressure at which the temperature will be reduced to 32° gives 10·998 lbs., showing that the error by the separate calculation of U_1 and U_2 scarcely exceeds ·05 lbs., or about 120 feet of height.

the wind, and ultimately again evaporated as it mingles with sufficient air to hold it in the state of vapour.*

When the air of the lower regions is more nearly saturated with vapour the temperature will not sink so low, the mountains will be colder than the air, and will act as condensers. In the case first supposed, of the air being originally at a temperature of 70°, and fully saturated with vapour, all that is condensed below about 11,550 ft. will be precipitated as rain above the temperature of 41°, and no snow will be produced until the air has ascended nearly to 14,500 ft. But if, instead of 7·75 grs., only half this quantity, or 3·88 grs., of vapour had existed in the air, condensation would commence at about 5,000 ft., and at a temperature of 45°; and at 9,500 ft. the temperature would be reduced to 32°, and snow would be produced, both from the further condensation of vapour and also from the water remaining suspended in the form of cloud. We have, therefore, these results—no snow with a given initial temperature and maximum evaporation, but snow produced with the same initial temperature and diminished evaporation.

If the initial temperature were higher, say 80°, and the air saturated with 10·57 grs. of vapour, the temperature at 9·5lbs. pressure, corresponding to an elevation of about 11,800 feet, would fall only to 54°, and would not reach 32° until a height of more than 18,000 ft. had been reached, so that nothing but rain, some degrees above the freezing temperature, would fall at the very highest Alpine elevations.

Or, if at this temperature the air were only half saturated with vapour the freezing point would only be reached when the pressure was reduced to 9 lbs., corresponding to an elevation of about 13,000 ft.

It is worthy of remark that a reduction of pressure from 14·25 to 9·5 lbs. causes a reduction of temperature from 80° to the extent of only 16°, when the air is fully saturated with vapour, whereas with the initial temperature of 70° the same reduction of pressure reduces the temperature by 19°.

If, on the other hand, the original temperature were considerably lower, say 50°, and the air saturated with 4·02 grs. of vapour, its reduction to 32°, and the condensation of 1·5 gr. of vapour, would be effected at a height of about 6,000 ft., where the pressure would be 11·55 lbs., and 2·52 grs. of vapour would remain uncondensed. So that at the height

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* The same explanation of the 'cloud-streamers' was given in a note by the present writer in the 'Alpine Journal' for December, 1863. Vol. i. p. 208.

of about 6,000 ft. the freezing point would be reached, and snow would begin to fall.

It appears, therefore, that with a given temperature to commence with, the greater the amount of vapour beyond that which can be held in suspension (either as vapour or cloud) at 32°, the less will be the snowfall up to a given elevation, and the greater must be the elevation attained before any snow begins to fall. An increased temperature has the same result. When heat and moisture both increase, the rainfall increases, but the temperature at higher elevations is less reduced, until all the precipitation is in the condition of warm rain and none of snow. This is well known to be the case in the Alps when the hot wind, called the Föhn, blows from the south heavily laden with vapour, and a few hours of the warm rainfall occasioned by it causes a greater waste of the glaciers than days of the hottest sun.

These results do not support the views favoured by Professor Tyndall that the greater glacial development of former times can be accounted for by increased evaporation occasioned by increased heat on some part of the earth's surface.* There might, however, be some plausibility in a contrary supposition. Supposing the temperature of the lower regions to be the same as now, if the supply of vapour were less, a larger proportion of it would fall as snow, and less as rain, so that a larger development of glacier would be the consequence of a diminished supply of moisture, without reduction of temperature from any other cause.

But it is said that what is required is not diminished heat, but more powerful condensers. We have already seen reason to conclude that the temperature of the mountains themselves exercises, at least in the production of snow, an inappreciable effect, if not a negative one. Condensation would also be caused by the intermingling of two quantities of air of different temperatures, both saturated with vapour. We will suppose two equal bodies of air to be thus mixed at a height of 10,000 ft., the pressure being 10 lbs. to the inch, one being of the temperature of 48°, with 3·76 grs. of vapour to the cubic foot, the other of 8°, with ·79 gr., together 4·55 grs. Two cubic feet of the mixed air at 28° would carry only 3·66 grs. But the condensation of ·45 gr. to the state of snow would suffice to raise the temperature of the air and remaining vapour to 31°, at which 4·10 grs. could remain uncondensed in two cubic feet, and no more snow would be produced. The ex-

* 'The Forms of Water,' § 56, p. 154.

pansion consequent on the elevation of the same bulk of air at 32° to a further height of about 1,050 ft. would account for the production of the same quantity of snow from aqueous vapour. In both cases the production of snow would be greatly increased if a considerable amount of water were suspended in the air in the form of cloud, and this will not much affect the comparison; but it is obvious that the mixture of bodies of air on a large scale will not occur readily or rapidly in nature, while the action of ascending currents is continually operating.

Another mode in which condensation is produced is by the diffusion of vapour passing from warm air heavily charged to colder air already saturated, and currents of cold air will act as condensers much more effectively in this manner than by mixture with the warmer air. If the warmer current is much above the freezing point, the vapour will be immediately condensed on passing from it to the colder air, and will fall as rain. But suppose the warmer air to be at 32°, and the colder air at zero, and both already saturated with 2·12 and 0·61 grs. of vapour respectively, and, for simplicity of calculation, suppose the two bodies of air of equal bulk and, as before, at an elevation of about 10,000 ft., the condensation of ·85 gr. of vapour per cubic foot of the colder air will raise its temperature to 10°·8, at which ·94 gr. of vapour can remain uncondensed, while an equal quantity remains in the warmer air. The actual snowfall would not be more than one-sixth of an inch (taking snow to be one-sixth the density of water) upon a square foot of surface for 2,000 cubic ft. of the total bulk of air. An equal quantity of air would have to be raised to an additional height of nearly 2,500 ft. to effect the condensation into snow of an equal quantity of vapour. But if in addition to the vapour about half a grain of water per cubic foot were held in suspension in the form of cloud, a very much less elevation, little more than 120 ft., would suffice to produce the same quantity of snow.

It seems, then, that the most powerful condenser now existing is the absorption of energy which results whenever a current of air is directed upwards; and it is difficult to conjecture what others more powerful can be conceived to have existed in former times, while this must have remained uniform.

One not unfrequent phenomenon of precipitation among the mountains remains to be noticed. In stormy weather the fall is often neither rain nor snow, but hail. It is evident from what has already been said that currents of air carrying with them large quantities of vapour may ascend to great heights without being reduced to the freezing point, while others of the same original temperature, but less vapour-laden, will be reduced below this point at comparatively low elevations. Suppose the former to be carried over the latter and then further chilled, the rain falling through the colder air will be frozen in its passage, and will reach the earth as hail.

Suggestions respecting the Process of determining Depth from an Observation of the Time taken by a Weight in its Descent By John R. Campbell.

The common method of getting a rough notion of the height, or, perhaps more correctly speaking, *depth* of a wall of rock by timing the descent of a stone is so old and well known that it would be waste of time to enter into a long description of it. The process may be applied to certain waterfalls where the pool into which the stream plunges is inaccessible to a climber, and which therefore cannot be measured by the aneroid; of such there are several examples in Norway. Probably, too, the depth of crevasses might occasionally be arrived at in this way. Indeed, with all its liability to error, supposing that error not to exceed what may be called a *reasonable* amount depending on the circumstances of the case, since it is the only plan that can be adopted in some instances without going to great trouble and expense—especially by a traveller in a mountain country—it may be fairly said to merit some consideration. The operation is not limited to the few cases in which a weight can be dropped vertically; the time occupied by the descent is the same if we can throw it horizontally forward so as to fall clear of the rock. I ought also to observe that the unavoidable error in the result is, as a rule, so great as to warrant our neglecting the resistance of the air in the calculation.

Now, when a stone of moderate size, such as one can easily throw, has to descend several hundred feet it becomes almost lost to view, and where it drops into the pool of a waterfall the spray may conceal it during the last second or more of its course; in both cases, therefore, we have a difficulty in determining the exact instant of its reaching the bottom. The question then arises,—Is it practicable to overcome this difficulty by using some other kind of weight in place of a stone?

The plan I am about to describe I would at once acknowledge possesses little claim to originality; I doubt not it bears much resemblance to more than one that have been tried at different times, although I have never seen an account of them.

My idea, briefly expressed, is to substitute for a stone a weighted *marroon* furnished with a detonating fuze that shall explode it on its striking the ground; and to compute the depth from the number of seconds elapsing between the instant of its being let go and that of the report being heard.

Fig. 1 represents the arrangement complete, and fig. 2 (drawn to a larger scale) is a section of the fuze with its striker. A is the marroon,