are accordingly difficult to follow. Perhaps this remark applies especially to his treatment of the central theorem, viz. the identification of the osmotic pressure of a dissolved gas with the pressure which would be exercised by the gas alone if it occupied the same total volume in the absence of the solvent. From this follows the formal extension of Avogadro's law to the osmotic pressure of dissolved gases, and thence by a natural hypothesis to the osmotic pressure of other dissolved substances, even although they may not be capable of existing in the gaseous condition. If I suggest a somewhat modified treatment, it is not that I see any unsoundness in van t' Hoff's argument, but because of the importance of regarding a matter of this kind from various points of view.

Let us suppose that we have to deal with an involatile liquid solvent, and that its volume, at the constant temperature of our operations, is unaltered by the dissolved gas—a question to which we shall return. We start with a volume $v$ of gas under pressure $p_0$, and with a volume V of liquid just sufficient to dissolve the gas under the same pressure, and we propose to find what amount of work (positive or negative) must be done in order to bring the gas into solution reversibly. If we bring the gas at pressure $p_0$ into contact with the liquid, solution takes place irreversibly, but this difficulty may be overcome by a method which I employed for a similar purpose many years ago.[1] We begin by expanding the gas until its rarity is such that no sensible dissipation of energy occurs when contact with the liquid is established. The gas is then compressed and solution progresses under rising pressure until just as the gas disappears the pressure rises to $p_0$. The operations are to be conducted at constant temperature, and so slowly that the condition never deviates sensibly from that of equilibrium. The process is accordingly reversible.

In order to calculate the amount of work involved in accordance with the laws of Boyle and Henry, we may conveniently imagine the liquid and gas to be confined under a piston in a cylinder of unit cross-section. During the first stage contact is prevented by a partition inserted at the surface of the liquid. If the distance of the piston from this surface be $x$, we have initially $x=v$. At any stage of the expansion ($x$) the pressure $p$ is given by $p=p_0v/x$, and the work gained during the expansion is represented by

$$p_0v\int_v^x \frac{dx}{x} = p_0v \log \frac{x}{v},$$

$x$ being a very large multiple of $v$. During the condensation, after the partition has been removed, the pressure upon the piston in a given position $x$ is less than before. For the gas which was previously confined to the space $x$ is now partly in solution. If $s$ denote the solubility, the available volume is practically increased in the ratio $x : x + s\mathrm{V}$, so that the pressure in position $x$ is now given by

$$p = p_0v/(x + s\mathrm{V}),$$

and the work required to be done during the compression is

$$p_0v\int_0^x \frac{dx}{x+s\mathrm{V}} = p_0v \log \frac{x+s\mathrm{V}}{s\mathrm{V}}.$$

On the whole the work lost during the double operation is

$$p_0v\left\{\log \frac{x+s\mathrm{V}}{x} + \log \frac{v}{s\mathrm{V}}\right\},$$

and of this the first part must be omitted, as $x$ is indefinitely great. As regards the second part, we see that it is zero, since by supposition the quantity of liquid is such as to be just capable of dissolving the gas, so that $s\mathrm{V}=v$. The conclusion then is that, upon the whole, there is no gain or loss of work in passing reversibly from the initial to the final state of things.

The remainder of the cycle, in which the gas is removed from solution and restored to its original state, may now be effected by the osmotic process of van t' Hoff.[1] For this purpose one "semi-permeable membrane," permeable to gas but not to liquid, is introduced just under the piston which rests at the surface of the liquid. A second, permeable to liquid but not to gas, is substituted as a piston for the bottom of the cylinder, and may be backed upon its lower side by pure solvent. By suitable proportional motions of the two pistons, the upper one being raised through the space $v$, and the lower through the space V, the gas may be expelled, the pressure of the gas retaining the constant value $p_0$, and the liquid (which has not yet been expelled) retaining a constant strength, and therefore a constant osmotic pressure P. When the expulsion is complete, the work done upon the lower piston is PV, and that recovered from the gas is $p_0v$, upon the whole $\mathrm{PV}-p_0v$. Since this process, as well as the first, is reversible, and since the whole cycle has been conducted at constant temperature, it follows from the *second* law of thermo-dynamics that no work is lost or gained during the cycle, or that

$$\mathrm{PV} = p_0v.$$

The osmotic pressure P is thus determined, and it is evident that its value is that of the pressure which the gas, as a gas, would exert in space V.

The objection may perhaps be taken that the assumption of unaltered volume of the liquid as the gas dissolves in it unduly limits the application of the argument. It is true that when finite pressures are in question, an expansion (or contraction) of the liquid would complicate the results; but we are concerned only, or at any rate primarily, with the osmotic pressure of *dilute* solutions. In this case the complications spoken of relate only to the second order of small quantities, and in our theory are accordingly to be dismissed.

January 8. RAYLEIGH.

[1] "On the Work that may be gained during the Mixing of Gases," *Phil. Mag.* vol. xlix. p. 311, 1875.

[1] *Phil. Mag.*, vol. xxvi. p. 88, 1888

## THE BOG-SLIDE OF KNOCKNAGEEHA, IN THE COUNTY OF KERRY.

AT about three a.m. on Monday, December 28, 1896, a catastrophe occurred some twelve miles north-east of Killarney, of which mention has been already made in these columns (NATURE, vol. lv. p. 205). A bog gave way at its lower edge, and precipitated itself as a black peaty flood into the valley of the Ownacree River. In the upper part of its course it unfortunately overwhelmed the cottage of Cornelius Donnelly, carrying away the structure and its eight occupants. Five of the bodies were recovered, with considerable difficulty, by January 3, when the mass had come practically to a standstill. In the lower part of its course, it flooded a number of farm-lands upon the slopes of the valley, and seriously threatened the cottage of Jeremiah Lyne, rising some five feet against its wall. Even at the junction of the Ownacree and the Flesk, one of the great feeders of the Lower Lake of Killarney, the banks were smeared over with a peaty mud, ten miles from the point of origin of the bog-slide; while a quantity of the material was carried another nine miles west into the Lower Lake itself.

While the first accounts of the disaster were naturally exaggerated, and even contradictory, coming as they did from places on opposite sides of the peaty watershed, an inspection of the area leaves no doubt as to the magnitude of the bog-slide. Such phenomena are not unknown in Ireland, one being recorded from the County of Galway in 1745, and another

having been reported on by Sir R. Griffith in 1821 ("Report Relative to the Moving Bog of Kilmaleady in the King's County," *Journ. Roy. Dublin Soc.*, vol. i.). In the latter case, 150 acres became covered with the products to a depth of eight to ten feet, and the flow extended from the edge of the bog one and a half miles down a valley. Probably in all cases such flows are merely a rapid extension of those "creeping" processes which produce rifts and areas of subsidence in bogs formed upon a slope.

The scene of the present bog-slide lies among Carboniferous rocks, and is included in Sheet 174 of the 1-inch Ordnance Map of Ireland (Fig. 1). A perfectly straight road runs N.N.W. from Shinnagh House, which is near the railway; at the cottages of Lisheen a branch runs west, meeting four other roads in the grass-grown quarries of Carraundulkeen. (I use the spelling of the Ordnance Survey throughout.) The bog in which the slip occurred lies between the road from Lisheen and that running almost north from the quarries, which is locally known as the Kingwilliamstown road. It is a brown almost level upland, a mile across, mainly in the townland of Knocknageeha, and is bounded on the north and south by enclosed and cultivated hills, which rise from 780 feet to 847 feet above the sea. The highest point recorded in the bog is 776 feet, and there is a fall of 1 in 38 between this and the bridge between the quarries. The streams on this side flow to the west coast, while the east side of the bog drains direct into the Blackwater.

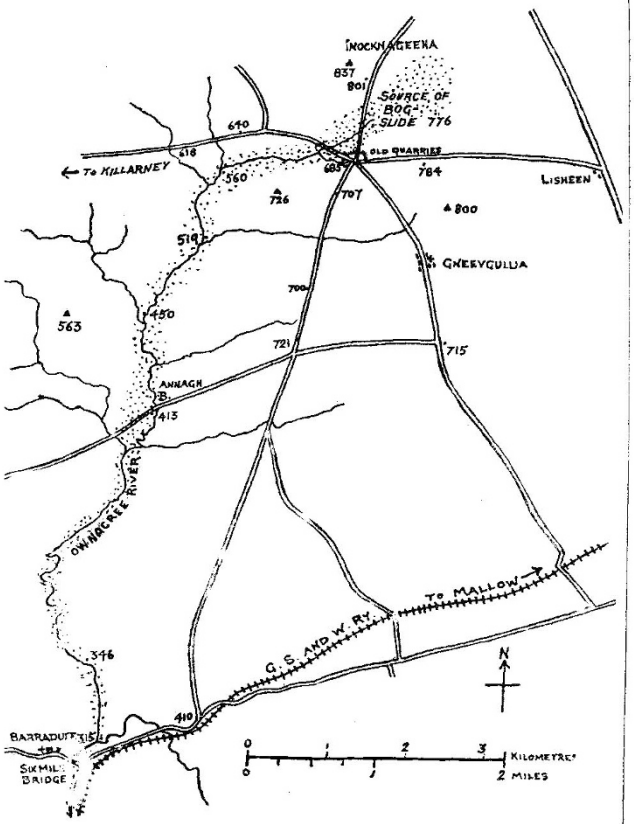


FIG. 1.—Sketch-map showing the site of the Bog-slide, from the maps of the Ordnance Survey. Heights in feet. The course of the flow is indicated by the dotted area.

Several deep peat-cuts existed in the bog, perpendicular to the direction of its subsequent flow, and these have the appearance of rifts or "faults" at a distance. But the lost portion seems to have oozed out from below a large area of the superficial peat, lowering the surface into a series of hummocky and very irregular steps. At the same time, great masses of the surface, with tufts of grass adhering to them, were floated down and hurried into the valley, looking, as one man told me, "as large as houses."

The flow appears to have been rapid and silent, though the noise of the storm which raged through Sunday night kept many of the cottagers awake. Even within a few hundred yards of Donnelly's house, no suspicion of the fate of the unhappy family was raised, until dawn revealed the black flood tossing, and still hurrying down the valley. A young peasant, living close to the edge of the flow, told me that he was roused only by the bellowing of his cow; in another case, a man went at about 4 a.m. to a point three miles down the valley to remove two calves, which he intended to drive into Killarney. He was then almost overtaken by the rise of the peat-flood at Annagh Bridge. I conclude, therefore, that no unusual sound or movement of the earth occurred, such as might have warned him of the coming danger.

FIG. 2.—Broken roadway, with meadows submerged by the peat-flow, at Annagh Bridge. Foreground of heaped-up peat-mud and bog-timber. Lyne's cottage in the distance.

The full flood first attacked the Kingwilliamstown road, on the east side of which the bog abutted. It filled up the hollow, climbed the embankment, and fell over the western side like a very fluid lava-flow. The guiding-line here was the course of the streamlet that drained the bog into the Ownacree River. Probably the road itself has been carried away beneath the thick mass now covering its site, and communication with the north is likely to remain cut off for some weeks. On January 3, movement had ceased at this point, but the embankment on which the road runs alone prevented a further down-rush.

Donnelly's cottage stood on the west side of this road, and was totally swept away. Its thatched roof was seen floating for a time, but the house is said to have been built of loose stones, and rapidly succumbed. The bodies recovered were found at various points in the first four miles of the flow.

The Royal Dublin Society have appointed a Commission, consisting of Prof. Sollas, F.R.S., and Messrs. De Lap, A. F. Dixon, and R. Lloyd Praeger, who may be trusted to give us an accurate survey of the flow; the

present paper will therefore be concerned with its broader geological aspects. Viewed from any of the neighbouring spurs, the valley of the Ownacree (the "Quagmire River" of the Ordnance Survey) now seems occupied by a black flood, winding with the course of the original stream. Here and there lake-like expansions occur, with pools of water on their surface; and, lower down the valley, the stream asserts itself, and is now cutting out a channel through the débris, or, rather, is washing out its original course. Without an intimate acquaintance with the country, it is difficult to know what changes have occurred in the form of the true valley-floor; but the local constabulary assert (*Freeman's Journal*, January 2, 1897) that a considerable deepening of the valley has resulted in places from the scouring action of the flow. This obviously applies only to the first two miles or so below the quarries, where the stream originally ran over a flank of the great Annagh bog. At and below Annagh Bridge no trace of any deepening is to be seen; the torrent is merely washing its way clean again, and revealing the original boulders on its floor.

To return to details, the passage of the flow across the western road, between Quarry Lodge and the older quarries, resulted in the filling up of a limestone-quarry and the destruction of the embankment of the road, together with its double hedges. Judging by the state of things at Annagh Bridge, the upper bridge may perhaps be found also standing, when the peat-flood can be cleared away. The destruction here is, however, considerable, and the oozing of the material through the hedges reminds one of the behaviour of some of the thin lava-sheets of Hawaii. Great stems and roots of timber, formerly buried in the upper bog, have been floated down, and stick up fantastically, like arms waving from the flood.

The main road to Killarney is thus effectually breached; and a still more striking scene occurs on the parallel road at Annagh Bridge (Fig. 2). Here the floor of the valley was flat for nearly half a mile west of the bridge, and was divided into a number of fields. The peat has covered the whole of these, and climbed, as has been said, against the wall of Lyne's cottage. The road is broken into sections and seems utterly destroyed; and bog-timber, which is abundant in this district, juts out everywhere above the slime. The peat has left traces on the top of the buttresses of the bridge, six feet above the present level of the water; and movements were noticed here in the subsiding flow a week after the catastrophe.

After this wild scene, the valley narrows, and the black borders to the stream show the height to which the flood first rose; every boulder has a bank of débris behind it, and islets of peat, bog-timber, and grassy tussocks have risen in the middle of the stream. The piers of Six-Mile Bridge, close to Barraduff, six miles from the original bog, are still clogged with timber, and show peat-patches a good five feet above the stream. Even travellers by rail can trace from this point downwards the black deposits on the banks of the Ownacree, down to the viaduct before Headford Junction.

As to the origin of the bog-slide, it must be compared, as already hinted, with the phenomena of surface-creep, which are strikingly illustrated by the stone rivers of the Falkland Isles and the constantly occurring landslides of the taluses of Tyrol. The ridging of soils upon steep hillsides is a well-known and milder form of this sliding motion; and a field laid out upon a slope, in an even moderately rainy climate, may be considered as being always added to at the upper end, and carried away down-hill at the lower. In peat-bogs, the water finds its way out in numerous channels into the main stream of some neighbouring valley; and the banks of these channels are always in a state of flux. During stormy weather, the black saturated lower layers of the bog are washed out in far larger quantity than the brown and drier upper layers. Rifts and signs of movement in the latter will then readily occur.

As Sir R. Griffith pointed out in 1821, there is little cohesion between the water-logged lower layers and the impermeable clay or other material which underlies the whole, and which allows, in the first instance, of the accumulation of the bog. The moving bog in the King's County was accounted for by the occurrence of a dry season, during which extraordinary cuttings were made, giving a face of thirty feet. The pulpy lower layers were thus reached, and were set free, carrying away the upper masses on their surface. The process is analogous to that which forms caverns in many lava-flows, the fluid lower portion becoming liberated and rushing out from under the upper part.

Similarly, the deep cutting of the bog of Knocknageeha may have been injudicious in so wet an area. It is possible that official inspection is required in these matters, as in more elaborate quarrying operations; and the loss of life in the present instance makes a consideration of the condition of other bogs at least desirable. But the immediate cause of the flow seems to have been the heavy rainfall of December 1896, which raised the level of the water in the workings and the level of saturation in the bog. Even in broad daylight it would have been impossible to check the movement, when once the Kingwilliamstown road had been overpowered. The slope on which the bog moved, making in the first mile an approximate allowance for the original thickness of the peat in Knocknageeha, falls about 120 feet in the first mile, 100 feet in the second, 95 feet in the third, and 45 feet in the fourth. The fall of the valley-floor as far as Annagh Bridge is thus about one hundred feet per mile, decreasing rapidly before the bridge; and it may be remembered, for future guidance, that this fall is sufficient to allow of a bog-slide of truly catastrophic character.

GRENVILLE A. J. COLE.

## NOTES.

IT is stated that Sir Joseph Lister, on being raised to the peerage, has selected the title of Lord Lister.

LORD KELVIN and Prof. Simon Newcomb have been elected honorary members of the St. Petersburg Academy of Sciences, and Lord Rayleigh has been elected a corresponding member.

THE Geological Society of London will this year award its medals and funds as follows:—The Wollaston Medal to W. H. Hudleston, F.R.S.; the Murchison Medal and part of the Fund to Horace B. Woodward, F.R.S.; the Lyell Medal and part of the Fund to Dr. G. J. Hinde, F.R.S.; the Bigsby Medal to Clement Reid; the proceeds of the Wollaston Fund to F. A. Bather; the balance of the proceeds of the Murchison Fund to S. S. Buckman; the balance of the proceeds of the Lyell Fund to W. J. Lewis Abbott and J. Lomas.

ANOTHER instance of the interest which the German Government takes in the advancement of science is afforded by the fact that an item in the Prussian estimates is a vote of 50,000 marks to the Ministry of Public Instruction for investigations with the Röntgen rays. The vote (says the Berlin correspondent of the *Times*) is justified by a reference to the importance which the new invention has been shown to possess in the spheres of physics, anatomy, physiology, zoology, botany, and kindred sciences. The object of the grant is to enable institutes and certain men of science to procure the necessary apparatus, and to defray the expense of exhaustive experiments.

THE Royal Academy of Sciences of Turin announces that the term for competition for scientific works and discoveries made in the four previous years 1893-96, to which only Italian authors