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POSSIBLE CAUSES OF THE VOLCANIC ACTIVITY AT LASSEN PEAK.*

BY

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My appearance before you to-day is due entirely to your watchful Secretary, who has discovered me searching for an earthquake within the boundaries of California and has very promptly summoned me to give an account of myself before this body. He has also asked me, very pertinently, to explain what I proposed to do with the earthquake in case I found it. It is a fair question.

Most of you will recall that on Memorial Day, in the year 1914, Lassen Peak broke out into activity with an explosion of ash-laden steam within the summit crater, which was witnessed by a number of people. Forest rangers climbed the mountain next day and found there, inside the old crater bowl, a small explosion-vent some 40 feet long and 25 feet wide with two cracks extending east and west from the opening to a distance of a hundred feet or more. The crater bowl was oval in shape, ten to twelve hundred feet in diameter, about 350 feet deep from the bottom to the highest point of the rim, and was rarely free

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from snow at any season of the year. In the winter time the accumulation of snow usually amounts to 30 or 40 feet, which does not melt to any considerable extent at this elevation (10,466 feet) before the middle of May. The explosion was followed by considerable steaming, and the rangers noted streams of water from the melting snow pouring into the small explosion vent and the cracks extending out from it. Very little attention has been paid to these two cracks by anyone who saw them or who has since learned of their existence. I shall ask you, however, to bear these in mind, for they have much to do with the search for the earthquake for which I am to account to you.

Other explosions followed this one at intervals of two or three days throughout the summer and autumn, increasing gradually both in duration and intensity. Many of the more powerful out-breaks lasted for four or five hours and steam clouds, black with ash, rose to a height of 10,000 feet or more above the summit. The country roundabout the mountain was strewn with ash and stones up to a foot or more in size for two or three miles. These rested on the snow during the early eruptions, and as long as the snow lasted, showing that they were quite cold at the time when they were thrown out. In the winter season following, no very accurate record was kept of these occurrences, for the mountain is shrouded in cloud and snow during that season and is often invisible for periods of several days or weeks.

The explosion vent grew in magnitude during this interval until it included nearly all of the old crater bowl. An ascent over the snow in March of 1915 showed a hole nearly a thousand feet in diameter, with steam emerging at several points, notably at the west end, where there was a notch in the rim toward which one of the two original cracks had been directed.

This gradually increasing activity culminated on the night of the 19th of May, 1915, almost exactly a year after the first eruption, in a terrific outbreak, followed by a mud flow on the northeast slope of the mountain, which devastated the valleys of Hat Creek and Lost Creek for some twenty miles.

It was on this evening also, about nine o'clock, when the only authentic appearance of red-hot rocks was noted. Mr. J. R. Milford and a party of friends were watching the volcano from the windward (west) side, which was the only direction from which it was clearly visible on that night. Mr. Milford has given

a very graphic description of the glow at the top of the mountain illuminating the great cloud, and the gradual appearance of a red line marking the notch in the crater rim on the west side, which grew in intensity until the crater seemed to overflow like a great pot of slag forming momentary trails of red down the western slope of the peak. This operation he saw several times repeated between the hours of nine and ten, after which the activity diminished until it was no longer visible.

Closer inspection of this side of the mountain afterward does not verify all the details of Mr. Milford's description, though there is no doubt that he saw glowing material at the summit and the glow on the clouds. There is no appearance of flow structure in the lava which now fills the western notch, and furthermore at the temperature of red heat this lava is solid, not liquid. It was therefore not a lava stream which he saw, but the volcano plug itself thrust upward into the notch as a result of the pressure from below, during which red-hot material, though still solid, was exposed. The breaking up of these hot rocks and the fragments which rolled down the mountainside gave to Mr. Milford the impression of flow movement at a distance of twenty miles.

Notwithstanding the spectacular character of this appearance of red-hot lava and the tremendous explosions with which it was accompanied, this was not the most conspicuous effect of the night's activity. On the northeast slope of the mountain a mud flow developed which passed down Lost Creek and over the divide into Hat Creek, then following and laying waste both valleys for twenty miles or more to the northward. Newspapers and contemporary publications represented this mud flow to have come directly out of the crater, but this was not the case. Mr. B. F. Loomis, of Viola, one of the keenest observers of the mountain during this period, states this case briefly and succinctly:

"I do not believe that any hot water poured out of the crater as such at any time. Of course not. It is unthinkable that water, either cold or hot, would flow over the crater rim in gentle ripples while hot rocks and mud bombs were being hurled into the air a mile."

More deliberate observation afterward reveals the fact that the first evidences of the mud flow occur about 1500 feet below the summit. Here, in a bay of the mountain, there was stored up from the previous winter, a mass of snow and ice which is

never completely melted in a normal year. Its depth has been variously estimated at from 50 to 100 feet. With such a mass of snow upon which the condensed steam and hot ash from the fearful explosions of that night fell, abundant material was furnished for an avalanche down Lost Creek Valley from 10 to 20 feet in depth.

Still, such an avalanche of mud and water, fearful though it was, would not have created the devastation afterward found there, without the release of forces of even more awe-inspiring magnitude. The Forest Service estimates that five million feet of primæval forest timber stood in this valley before the eruption of May 19th. Afterward it was completely gone, not a stump or root or trace of snow remained to indicate what had been on the valley floor before this eruption. Indeed the trees were removed for some hundreds of feet above the uppermost limit reached by the flood.

There is only one agency competent to account for such complete devastation, and that is a horizontal blast from the crater itself, shot directly into this mass of timber and snow. Furthermore, there is abundance of direct evidence of the progress of this blast, for on the sides of the valley far above the boundaries of the mud flow, trees are down which were not removed, and they lie without exception with their tops pointing straight away from the crater in spite of the fact that they lie upon steep hillsides. Not only this, but every tree has been subjected to a terrific sand-blast, which has carried away the bark on the side toward the volcano while it remains undisturbed on the protected side. Trees which are broken off instead of uprooted have left behind stumps completely rounded off by the blast, and grains of volcanic sand have been driven into these trunks for an inch. These corridors of parallel tree trunks extend for nearly two miles on both sides of the valley far above any point reached by the flow of mud.

It could also be observed in the weeks following this eruption that the foliage of the standing trees on the borders of the devastated area was singed by the heat of the blast. Farther on in the region beyond the mouth of the valley, where the blast had spent its force, all the foliage was brown for a half mile or more.

Notwithstanding this no fires were kindled, which would seem to indicate plainly either that the blast was momentary or that its temperature fell somewhat short of the temperature necessary to

kindle even dead twigs. Probably both of these conclusions are justified.

The total extent of the blast was about four and one-half miles in a direct line from the mountain summit, and the width of the zone of complete devastation was about a mile and a quarter at its widest point. Notwithstanding this catastrophic outburst there was no eye-witness of the occurrence of any of these phenomena. It happened at night and the first evidence of it to reach the public came in a telegram from the forest ranger stationed on Hat Creek, several miles below, who reported a devastating flood of milk-warm water and mud which was covering the meadows in the northern reaches of Hat Creek Valley, carrying away out-buildings and rendering the cattle ranches uninhabitable. Fortunately the number of persons in the valley thus early in the season was small and no live stock had yet been brought in, so that no actual loss of life occurred, but it is safe to say that if a city had been located in Hat Creek Valley at the point where it came under the direct power of the blast, as was the case in the great eruption of Mt. Pelée in Martinique (1902), the loss of life might have been as complete as it was then.

Following this outburst the volcano remained active more or less continuously during the next three days, being shrouded in smoke and difficult of observation during most of that period. At five o'clock on the afternoon of the 22nd came the greatest eruption of all, in which the volcano cloud rose to a height of more than five miles and could be plainly seen for a hundred miles or more in any direction. This was the culminating outbreak of the entire period of activity. Since that time the explosions have diminished gradually in violence until 1918, when they ceased entirely.

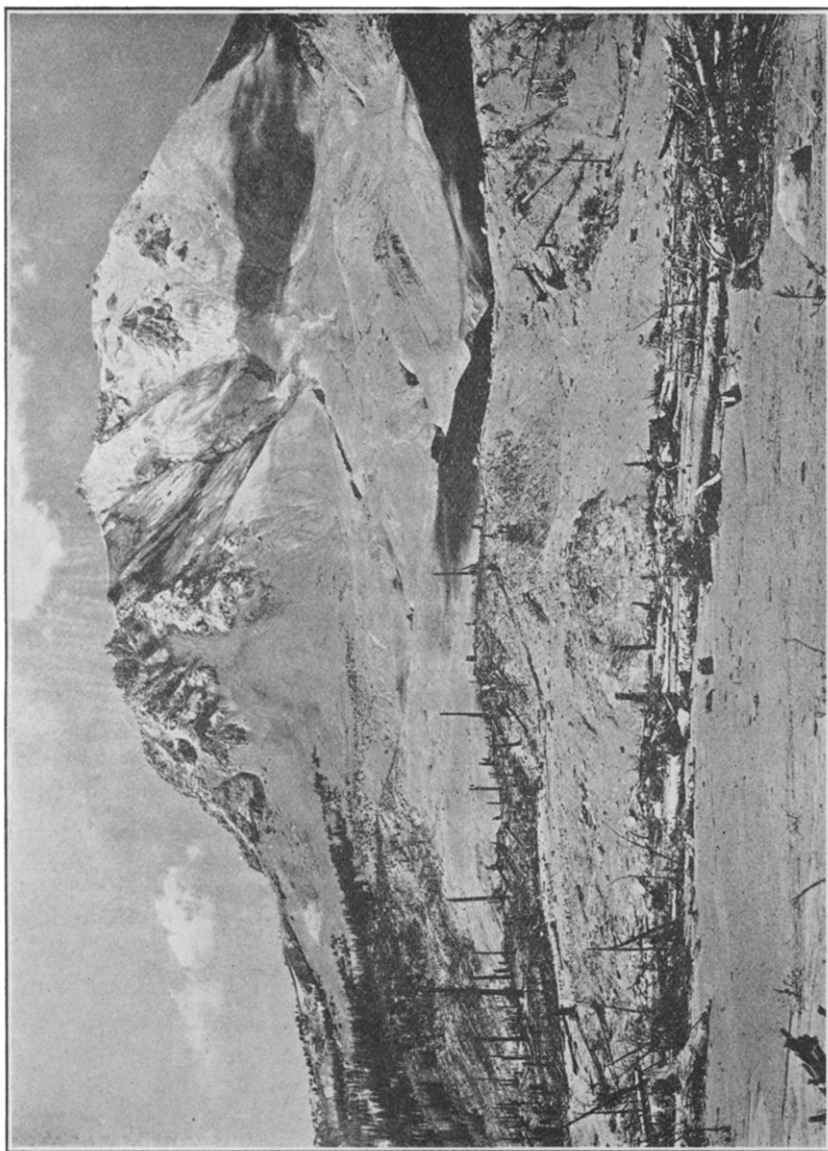
This culminating eruption of May 22, 1915, was also accompanied by a horizontal blast bursting from the same opening and proceeding in nearly the same direction as the previous one. The snow and the trees having been carried away for the most part by the first blast, less water and mud were available for the second flow, and practically no fresh damage was done. On the north slope of Lost Creek Valley a number of trees which had escaped the first blast were laid down like the earlier ones in parallel rows directly away from the crater, regardless of the lay of the land. In both of these blasts boulders up to 15 or 20 tons in weight

were dislodged from the top of the mountain and borne by the flood into the valley below, some for a distance of five or six miles.

The mechanism of these horizontal blasts is interesting. At the beginning, or shortly before the activity of the 19th, the crater floor was raised from below until it stood nearly level with the crater rim, a vertical movement of more than 300 feet. Had it gone higher the plug would undoubtedly have been dislodged from the vent entirely, and a flow of lava would have resulted. As it was the enchained pressure of volatile matter (mainly water) within the mountain appears to have found vent on the 22nd without actually blowing off the top of the mountain, and thereafter to have remained powerless to open the main crater conduit. It was as though the lava plug with which the volcano had remained sealed for so many years had been started upward by pressure from within which had then found release at the weakest point in the inclosing chamber. This happened not to be through the plug itself but below the plug on the northeast side of the mountain, much as a gas explosion in a kitchen stove might do, raising the lid and escaping in a horizontal blast from beneath it. After the emergence of these horizontal blasts the pressure was released and the lid collapsed. Its present appearance indicates rupture by such forces at a great many points of the exposed surface.

The mechanism of this entire sequence of volcanic activity can, I think, be inferred quite simply from the phenomena which have been described to you, and an appropriate application of the laws of physical chemistry. The great volcanic clouds, which characterized the explosions, were mainly of dust-laden steam. There is extremely little evidence of the participation of sulphur or other chemically active ingredients from beginning to end of this series of outbreaks. This will serve to establish the fact that no heat arising from chemical action within the volcano contributed to the reactions which occurred. This conclusion is supported by the further observation that, with a single minor exception, no fires were kindled by the blast, and, with the exception of the night of the 19th of May, 1915, no evidence of red heat was visible on the top of the mountain. Compared with other volcanoes which have been studied the volcanic phenomena at Lassen Peak occurred at comparatively low temperatures, certainly not above red heat. Also it should be noticed that Lassen Peak is located in a region of considerable rainfall, that the summit crater is almost never

FIG. 1.



View of Lassen Peak from the northeast showing the devastated mountainside together with the upper valley of Hat Creek and Lost Creek taken from a point between four and five miles from the summit, July 22, 1915.

free from snow, and that several streams of considerable size have their sources high on the flanks of the mountain. We are therefore dealing with a cooling volcano hearth in a region of abundant water supply.

Considering such dynamic systems, it is usual to assume that temperature and pressure rise and fall together. If the temperature were to rise the pressure would be increased, and if it were to fall the pressure would fall with it. In such reasoning, however, we overlook a vital factor in the consideration of silicate systems in the presence of considerable quantities of water. Laboratory measurements have shown that silicate solutions (rock magma) of high silica content easily take up ten or fifteen per cent. of water when in liquid condition under pressure and carry it in solution. In accord with this we also find in nature occasional pitch-stones and obsidians, which have cooled from the magma without crystallization, also containing 10 per cent. or more of water. On the other hand, crystalline rocks, as shown by the thousands of analyses made of them, contain no more than 1.5 per cent. of water. In order to crystallize, therefore, a high-silica magma, containing 10 per cent. of water, must divest itself of more than 80 per cent. of this water in the process of crystallization. Such a large proportion of the water content set free in the hot volcano chamber will increase the pressure enormously, even though the crystallizing operation is a cooling process.

By way of illustration of this, silicate mixtures have been prepared in the laboratory, inclosed in bombs with a sufficient quantity of water, and the pressure measured over a series of falling temperatures. It has been demonstrated, for example, that a simple mixture of silica, potash and water, which begins to crystallize at 500° C., will discharge this water when the temperature is lowered from 500° to 420° and the water thus set free will immediately develop a pressure appropriate to that high temperature. In this system the pressure may increase seven-fold (from 50 atmospheres to 340 atmospheres) in cooling through this interval of 80 degrees.

Without going further into the physico-chemical details, this process finds direct application at Lassen Peak. The magma is an andesite, high in silica, and so far as we have evidence of the heat conditions it is in process of crystallization at a comparatively

low temperature. The available water in the region is abundant to support the assumption that the percentage of water carried in the magma is large. The enormous quantities of water given off in the 300 or more explosions of record, some of which continued for several hours, still further support this assumption. The increase of water pressure depending upon the progress of crystallization is therefore appropriate to explain such a long series of explosions.

If this exposition has been clear Lassen Peak has been shown to be a true volcano and not a geyser, as sometimes asserted, that is to say, a chamber in which liquid magma (lava) is gradually crystallizing, located in a region which supplies to it an abundance of water. All of the explosions were steam explosions to which was added only the dust carried in the conduit or generated by attrition during the explosions. It is therefore from the engineering standpoint a cooling system to which no new energy is being supplied through chemical action of the kind which is characteristic of the volcanoes of Hawaii or of the Mediterranean.

It has been shown by laboratory experiments, in which all the factors were strictly measurable, that a silicate solution (lava), when crystallizing, sets free all of its water content above one or two per cent., and this water discharged in a closed chamber at a temperature of 600 or 700 degrees generates an enormous pressure within the chamber which may be sufficient to burst its bounds at the point of greatest weakness.

It remains to consider how such a process can produce a succession of explosions of gradually increasing intensity up to a culminating point and then gradually subside.

It is at this point that I wish to recall to your attention the two cracks in the crater floor which were discovered by the Forest Rangers shortly after the very first explosion at the summit. Considered as an explosion, this first outbreak was insignificant and not by any means adequate to explain the cracks. Still less are we able to recognize in it the outburst of 200 years of gradual crystallization and consequent accumulating steam pressure following the process above outlined. Such cumulative stresses should have been sufficient to blow off the top of the mountain, as once happened at Bandai San in Japan and at Katmai in Alaska. Suppose, however, that the temperatures within the mountain were relatively low, as every indication during the

period of explosive activity seems to establish, then crystallization was probably proceeding at a very slow rate in a magma of high viscosity which very probably was much undercooled. By that I mean that the liquid magma was so inert that crystallization was lagging, although it had already reached a temperature considerably below that at which crystallization would have occurred under more favorable conditions. Suppose further that into this inert mass there was suddenly introduced, through cracks at the top, a body of water, under a pressure head appropriate to the height of the mountain, which was speedily transformed to steam, which, under such circumstances, we know is quickly absorbed by the magma. The first effect of such an intrusion is to cause a considerable increase in the fluidity of the lava, and this in turn a considerable increase in the rate of crystallization. Water is coming in at a low pressure from one source, and in consequence of it water is released from another source (out of solution) at a high pressure. An increased rate of crystallization means an increased rate of setting free of the water content already impounded in solution in the inert lava. The resulting pressure increase might be expected to seek an outlet through the opening which had thus been broached in the crater floor, and a small explosion might result. An undercooled lava system, though inert if cool enough, is unstable, and once it is set in action through local increase of fluidity in this manner, the tendency to reach equilibrium (through crystallization) is strong. Consequently the action here indicated is likely to proceed rapidly and the rapidly accumulating pressure to find relief in successive explosions depending for their magnitude and frequency directly upon the rate of advancing crystallization and the increasing amount of participating magma as the successive explosions expose greater masses to the new and favorable conditions. This seems to me to account well for the low intensity of the initial outbreak and the gradual increase in volume and intensity as the crater floor was shattered by successive explosions and greater quantities of water were admitted to the volcano hearth, bringing an increasing quantity of crystallizing magma into an action which eventually becomes more or less self-perpetuating until all the available uncrystallized magma is participating. Then follows the culmination and subsidence.

This analysis, if correct, might lead to two alternative results. That the potential activity (pressure) within the mountain is due

to advancing crystallization, appears to be logically grounded and established by appropriate laboratory experiments. It could find release only in the breaking down of the resistance of the containing envelope, that is, the mountain itself. This might happen either from without or from within. If the release had come solely through accumulated pressure within, which eventually became adequate to overcome the normal resistance of the mountain, then a terrific explosion must have resulted through which the entire accumulation of energy would have found release in a single catastrophe. This obviously was not the case. If, on the other hand, the resistance of the mountain to the accumulated pressure within had somehow been weakened slightly by action from without, such as an earthquake crack, and this development of structural weakness had been followed by a succession of explosions extending it gradually, then we would seem to reach the counterpart of the present phenomenon.

It is for this reason that your Secretary found me searching for a record of an earthquake in California, one that occurred in April or May of 1914. Lassen Peak region is subject to earthquake disturbances, often of very noticeable magnitude, but no record exists of these local disturbances, either of their intensity, their direction, or their probable origin. So far as any records now available are concerned, we may not know whether the local earthquakes are to be regarded as possible causes or as effects of volcanic activity. For this reason I have been unable, so far, to verify my hypothesis fully, though I entertain no doubt of its substantial correctness, even without the record.

Speaking before the Commonwealth Club I feel free to emphasize our lack of knowledge of California earthquakes, for it was in this body, less than a year ago, that resolutions were passed urging a systematic study of the earthquakes of the west coast. It is probable that the need for such information in connection with volcanic activity at Lassen Peak will not impress you as a conspicuous and tangible need when compared with the need which is felt by engineers in the consideration of such problems as the proposed viaduct across San Francisco Bay, or the construction of buildings in regions peculiarly exposed to earthquake disturbance, or in connection with the water supply of our great cities, which, on this coast, frequently has to be drawn from the mountains many miles away. These are vital problems in California, and it

is a pleasure to see that this representative body stands ready to defend them as such. Anything less than systematic study and record is of little value in considering earthquake phenomena, as I will illustrate to you in a moment.

As a beginning of such study it will be interesting to you to know that on July 1st the U. S. Coast and Geodetic Survey began a new primary triangulation to extend from points on San Francisco Bay to Reno, Nevada, with the definite purpose of ascertaining whether or not there is a northward creep of the coastal region such as has been reported probable by the astronomers at Ukiah and at Lick Observatory. It is of the utmost importance to establish definitely whether there is such a creep or is not. For if the creep exists, and by its northward movement sets up a strain in the earth's crust, and if this crust when strained to the limit ruptures, producing earthquakes like that of 1906, then it is of the utmost importance that we should know the direction and rate of this drift, that we should know where the lines of weakness are located, where previous ruptures have occurred, which of these continue to be active and which are no longer so. This a primary triangulation will reveal.

It will interest you further to know that the U. S. Geological Survey, in coöperation with the Universities at Stanford and Berkeley, the Branner Society in the south, and the Seismological Society of America, whose President, Professor Willis, is with us to-day, have already been at work throughout the year gathering together information about these breaks or faults with the purpose of publishing a map showing where they are. These are the zones of mechanical weakness which, when they approach our large cities, are of the first economic importance.

There is also being built in Pasadena, through the courtesy of the California Institute of Technology, a new instrument designed especially for the purpose of studying local tremors and land slips. No such instrument, for the purpose of locating nearby disturbances of this kind, has been devised hitherto. If it proves successful the plan is to establish a number of stations equipped with them, through which to locate very exactly the direction of slips or tremors, and so to know not only the lines of weakness along which such disturbances may be propagated, but also the points of origin from which they may be expected.

You will recall the effort which was made in 1907 by the

California Earthquake Commission, in collaboration with government agencies, to obtain this information after the earthquake of 1906, but the surveys which were then made did not tell us positively either the direction or the magnitude of the displacement which had occurred, because the base-line then chosen was within the zone of the crustal creep, if there was one, and the consequent strain, and therefore within the zone affected by its release. Recognizing these limitations in the earlier effort, it is our hope and purpose not to be found short-sighted again. The astronomers are continuing their observations with additional instruments and, when supported by these surveys of the highest precision, which we hope may be continued for several years, we expect no movement within the coastal plain from Ukiah Observatory to the Mexican boundary to occur without our being able to ascertain precisely its direction, its magnitude, and its probable point of origin. It is my hope that the interest which has been shown by this most influential body in the inauguration of these studies and measurements by the Carnegie Institution of Washington and the scientific bureaus and institutions associated with it, may continue throughout their progress.

To emphasize to you the futility of personal evidence, as opposed to competent instrumental records, it may interest you to know that for a short time I thought to have found precisely the earthquake which I sought. A mining engineer, who was prospecting for values in the vicinity of Lassen Peak during April of 1914, assured me that he both felt and saw a considerable shock from his position a few miles to the east of the mountain, and that this disturbance proceeded visibly in the direction of the volcano crater itself. This direction of progress was also consistent with the general faulting of the region and therefore seemed to fulfil my expectations completely. But I thought best to inquire how he managed to see the earthquake as well as to feel it, and was told that it could be plainly followed by the thin line of dust cloud which marked its progress toward the mountain.

A short time afterward when I happened to meet my old associate in Lassen Peak exploration, Mr. Roy Sifford, who for twenty years has spent at least half of each year at the foot of the mountain, I took advantage of the occasion to ask him what the snow conditions were in the month of April within say

twenty miles of Lassen Peak. He replied at once that I could count on from five to six feet of snow at any point within twenty miles of Lassen at that time of the year. Just how it should be possible to observe an advancing dust cloud through six feet of snow was a puzzle which had the immediate effect of discouraging my interest in this particular evidence, and so my hope of completing the chain of circumstances which should explain the inception of volcanic activity at Lassen Peak in 1914 vanished. Perhaps I may yet be successful enough to find a more trustworthy clue. However that may be, this will serve to explain to you why I sought an earthquake in California this summer and the disposition which I proposed to make of it if found.

I thank you for your kind attention.

Manufacture of Vanillin by Electrolysis.—In the spring of 1897, a German patent was issued for a process for producing vanillin by subjecting isoeugenol to an electric current, the vanillin being formed by oxidation and appearing at the anode. The process was described in some detail, consisting essentially in placing in the anode cell a 15 per cent. solution of isoeugenol in an excess of sodium hydroxide, the cathode cell being charged with a 15 per cent. solution of sodium hydroxide. A current of about 5 volts and 6 amperes was recommended. The course of the action is followed from time to time by withdrawing small portions and testing for vanillin. A temperature of about 60° C. is advisable. When the action has progressed well, the anode liquid is shaken with ether which dissolves the vanillin and any unchanged isoeugenol. The vanillin is recovered by shaking with acid sulphite, and this compound decomposed in the usual way.

Notwithstanding the specific claims of this patent, Alexander Lowy and Catherine M. Moore, of the Department of Chemistry, University of Pittsburgh, found by careful experiments that the results stated cannot be obtained. Their work was communicated at the forty-second general meeting of the American Electrochemical Society in September last. All attempts to get an appreciable yield of vanillin failed. Vanillin, itself, was found to oxidize readily, and even if produced in the process will be at once converted into other substances. Experiments were also carried out in which sulphuric acid was used as the electrolyte, but also failed. In all the experiments a resinous substance was obtained. Statements are made in text-books that vanillin can be obtained electrolytically from isoeugenol, but such statements are not borne out by the investigation. If isoeugenol can be so converted, it must be under conditions different from those called for in the patent.

H. L.