A comprehensive treatment of this subject is given by Max Rubner.[1] The determination of the amount of sulphur dioxide in the smoke stream is much more simple, since the concentration of the gas is considerable. The principal difficulty where high stacks are in use is that the smoke stream shifts so rapidly that it is usually impossible to follow it. The best time for such a determination is at night, when the smoke often settles in a cloud in the valley.

Many interesting problems have arisen in this work which could not be solved on account of lack of time. It is possible that the flue dust, as assorted by the flues and chambers, would supply a good field for work on the rare elements. An analysis made several years ago gave 0.011 per cent. vanadium, 0.027 per cent. selenium, and 0.016 per cent. tellurium; while a qualitative examination for the ordinary elements showed, in addition, the presence of silver, lead, bismuth, copper, arsenic, iron, aluminium, manganese, zinc, barium, calcium, magnesium, sodium, ammonium, silica, water, sulphuric acid, chlorides, sulphides, sulphites, sulphates and a trace of organic matter. Other elements might have been present in traces. The dust from the flue near the stack, or in the stack itself, contains a considerable amount of concentrated sulphuric acid, while that from near the furnaces contains much less. To this latter, together with the arsenic with which it is associated, is probably due much of the spotting of leaves which is so common in smelter regions. This action of the flue dust is of far less importance than that of the sulphur dioxide[2] in affecting the growth of plants, in spite of some recent opinions to the contrary; but the arsenic of the dust may affect to a greater degree the value of the grasses, since it renders them poisonous.

In conclusion, we wish to express our special indebtedness to Dr. John Maxson Stillman, who has helped us very greatly in all of this work. We wish also to thank Captain D. W. Taylor for the design of the Pitot tube, Professor Robert Sibley for checking the calculations, and Professors W. R. Eckart, Jr., W. F. Durand, and Albert W. Smith, for aid, and for suggestions as to the determination of velocity.

THE UNIVERSITY OF MONTANA AND STANFORD UNIVERSITY, April 22, 1907.

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INJURY TO VEGETATION AND ANIMAL LIFE BY SMELTER FUMES

BY J. K. HAYWOOD.

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Before taking up the subject of the actual injury to vegetation and

[1] Rubner, Archiv. für Hygiene, LVII, 323-378; LIX, 91-149.

[2] For a comprehensive bibliography on the subject of damage by smelter smoke see: Haselhoff und Lindau, Die Beschädigung der Vegetation durch Rauch, Leipzig, 1903; Schroeder, J. v., u Reuss, C., Die Beschädigung der Vegetation durch Rauch und die Oberharzer Hüttenrauchschäden, Berlin, 1885.

animals by various smelter wastes a few words in regard to the wastes that might arise from a plant smelting sulphide copper ore, are necessary. Three wastes arise which may be injurious to vegetation or animals: First the sulphur contained in the ore is gradually given off during the various processes of smelting as sulphur dioxide which would have its injurious action on vegetation. Second, in case arsenic is present in the ores as it often is, notably at Anaconda, Mont., it is given off in the fumes from the smelter in volatile form and deposited on the surrounding land and crops, where it may be sufficient in amount to poison cattle browsing on pastures exposed to it, or living on hay cut from it. In case ores contain a considerable quantity of arsenic it is a common practice to recover as much of it as possible by passing the fumes through long cooling flues. This is done at Anaconda, Montana, where the fumes are passed through extremely long cooling flues, the condensed arsenic being obtained in the form of flue dust. Even under the best circumstances, however, some of the arsenic will escape from the top of the chimney along with the sulphur dioxide in the fumes. Third, the tailings from the water concentration of the ore are discharged into convenient streams; the slag is discharged in a finely divided form on a dump, and the "slime" is left in piles in the open air. Both of the latter are exposed to the percolation of any rain that might fall and the slag is also exposed to the action of the water discharged from the smelter. In consequence of the above the streams receiving the waste water from reduction plants, may contain a comparatively large amount of copper in suspension, and are apt to contain some copper in solution. If these streams are used for irrigation purposes, a possible source of injury to vegetation is to be taken into account in considering the action of the copper present on growing crops.

In the first case of this kind studied by the writer in the vicinity of Redding,[1] California, no complaint had been made of the injury from arsenic or from copper, so that the only problem considered was the action of sulphur dioxide fumes on the surrounding vegetation.

Although the results of this Redding investigation have been already published a resumé of the results obtained will be given, in order that the reader may understand further work that has since been carried out.

Injury to Vegetation by Sulphur Dioxide Fumes, near Redding, California. In carrying on this investigation it was first necessary to show whether or not sulphur dioxide was injurious to plant life, how small a quantity was injurious and through what organs of the plant such injury took place. Light is thrown on this subject by the work of foreign chemists. Freytag[2] showed that sulphur dioxide does not in-

[1] Bull. No. 89, Bureau of Chem., U. S. Dept. of Agr.

[2] Mitt. d. Konigl. landw. Akad. Poppelsdorf, 1869, 2.

jure the plant through the roots, by watering wheat, oats and peas with large amounts of dilute sulphurous acid and noting that the plants neither wilted nor was their crop yield reduced. Von Schroeder and Dumont[1] by an investigation on pines made in 1896 showed that the injury to vegetation by sulphur dioxide is not by means of the roots but through the leaves, and that even extremely minute quantities of sulphur dioxide are injurious. In a later investigation they showed that on fumigating pines 109 times with 1 part of sulphur dioxide to 100,000 parts of air, great injury was inflicted and that on fumigating a number of pines 583 times with 1 part of sulphur dioxide to 1,000,000 parts of air, injury was also to be noted.

The details of the work of the writer on injury to Australian pines and young cow peas are given in Bull. 89 of the Bureau of Chemistry. It is only necessary here to mention the results obtained.

1st. Pine trees fumigated 6 times with 1 part of sulphur dioxide to 100 parts of air showed great injury. All of the needles were drooping and nearly all had turned yellow or brown.

2nd. Pine trees fumigated 9 times with 1 part of sulphur dioxide to 1000 parts of air were greatly injured in the same manner as the plants just described.

3rd. Pine trees fumigated 50 times with 1 part of sulphur dioxide to 10,000 parts of air were badly injured.

4th. Cow peas fumigated 18 times with 1 part of sulphur dioxide to 10,000 parts of air lost all their leaves and could not be revived although carefully watered and tended outside the fumigation chamber.

5th. Pine trees fumigated 50 times with 1 part of sulphur dioxide to 30,000 parts of air showed decided injury.

It was next necessary to show that treating plants with sulphur dioxide increased the sulphur trioxide content of the leaves so that it was present in larger quantities in the treated plants than in the untreated ones. As a necessary consequence of such an increase the sulphur trioxide content of the ash of fumigated plants would be apt to be higher than that on an unfumigated plant.

In the work of Von Schroeder and Dumont previously mentioned, where different parts of the plants were treated with varying strengths of sulphur dioxide the sulphur trioxide content of the treated plants was in excess of that of the control plants in every case, and the percentage of sulphur trioxide in the ash of the treated plants was higher than that in the ash of the control plants. The same was found to be true on making analyses of the plants fumigated by the writer. From the above results a method was at once suggested for determining whether trees around a smelter were killed by the fumes or died from other causes.

[1] Therander forstl. Jahrb., 1896, 46:1.

The next step in the investigation was to see whether the dead and badly injured trees around the Mountain Copper Co.'s works near Redding, Cal., usually contained more sulphur trioxide than trees of the same species which stood close by in the same soil but were not killed. Of 25 pairs of trees examined in various directions from the smelter 80 per cent. contained more sulphur trioxide in the leaves of the injured trees than in the leaves of the uninjured ones, while only 20 per cent. showed the reverse. It was further shown that 80 per cent. of the injured trees contained a larger percentage of sulphur trioxide in the ash of the leaves than the uninjured trees.[1]

In a similar investigation in the vicinity of a zinc smelter at Lethmathe, Germany, reported in Haselhoff and Lindau's work on Injury to Vegetation by Fumes, one especially conclusive examination was made of the foliage of the surrounding vegetation. The worker here, instead of selecting the trees in groups of two from the same location, one injured and the other uninjured, took his injured trees from points near the smelter and his uninjured ones to compare with these from points much more distant from the smelter, but in the same direction. (Where this can be done the results are even more conclusive than the results obtained by the writer by his method, but unfortunately the rugged nature of the country in the vicinity of the smelter at Redding forbade the use of tion by Fumes, one especially conclusive examination was made of the 89 per cent. contained more sulphur trioxide both in the leaves themselves and the ash of the leaves of the injured trees than in the uninjured ones.

Three or four years later this same region around the zinc smelter was again examined and it was found, of 19 groups of trees examined all contained more sulphur trioxide in the leaves of the injured trees than in those of the uninjured ones.

It might be of interest to give some idea of the amount of sulphur dioxide given off by the plant of the Mountain Copper Co. each day. It was found that the ore contained about 41.5 per cent of sulphur and about 1,000 tons were smelted daily, so that approximately 748 tons of sulphur dioxide were given off into the atmosphere each day.

From this work in the vicinity of the smelter near Redding, California, the writer drew the following conclusions:

1st. Sulphur dioxide, when present in very minute amounts, kills vegetation.

2nd. Such injury shows itself by an increased sulphur trioxide content of the foliage.

3rd. The vegetation around the smelter for at least 3½ miles north, 9 miles south, 2¼ miles east, and 5 to 6 miles west, is greatly injured,

[1] For a full discussion of this subject see Bull. 89, Bur. Chem., U. S. Dept. Agr.

and less severe injury extends even beyond these limits for a considerable distance.

Injury to Vegetation By Sulphur Dioxide Fumes Around Ducktown, Tennessee. The next investigation of injury to vegetation by smelter fumes carried on by the writer was in the vicinity of Ducktown, Tenn.[1]

Here again the only injury complained of was that due to the action of sulphur dioxide on vegetation, so only this problem was studied. The chemist in this investigation was accompanied by one of the foresters of the Department of Agriculture, and only samples of those trees were collected which the forester was reasonably sure had not died from insect pests, forest fires, crowding, or other common causes of forest destruction.

Before going into the discussion of the chemical analyses a short account of the general situation of the smelters and the condition of the surrounding vegetation as it appeared to the writer, would not be out of place.

Location of Smelters and Appearance of Surrounding Vegetation. Two smelters are involved, 1st, the smelter of the Tennessee Copper Co., and the Smelter of the Ducktown Sulphur Copper and Iron Co. These are situated in a valley about 7 to 10 miles broad and approximately 20 miles long, from 1 to 2 miles S. W. and S. E. respectively, of Ducktown. To the east, west, and north fairly high mountains separate this valley from the adjoining country. Toward the south the valley is gradually lost in the foot hills of adjacent mountains. At the northern end of this valley the Hiwassee River makes a cut through the mountains in approximately an easterly and westerly direction. At about the middle of the long diameter of this valley the Ocoee River, running in approximately a north westerly and southeasterly direction, flows across the valley and cuts through the mountains on the western side of the valley.

The direction of prevailing winds during the summer seems to be in a north westerly and south easterly direction. If the fumes are the cause of the destruction of the vegetation one would expect the greatest damage in this valley in the direction of the prevailing winds and in the cuts made by the rivers through the mountains. That such is the true distribution of the damage will be brought out later.

A careful general inspection of the country around the smelter shows that the area of very severe damage extends around the smelter in the form of an irregular ellipse, with its long diameter in a N.N.W. and S.S.E. direction, the total length of the long diameter is about 22 miles, and of the short diameter about 15 miles. The area of perceptible damage extends beyond the above area for a distance of 1 to 6 miles. A second trip was made to this affected area a year later than when the above

[1] The full details of this work will be given in a future bulletin of the Bureau of Chem. Only the principal results obtained are given here.

observations were made, and it was found that severe damage could be noted in isolated areas about 20 miles south of the smelters.

In connection with this tour of observation, one point should be mentioned which came under the observation of the writer in a very forcible manner, and that is that different species of trees vary greatly in their susceptibility to sulphur dioxide fumes. For example, in the territory around Ducktown the white pines were injured or entirely dead when no other trees showed any injurious effect in the slightest degree. On the other hand, the post and white oaks and red maples were very resistant to the fumes and would grow very close to the smelter without seeming injury. Between these two limits were the Black, Red, Spanish, and Black Jack Oaks, and the yellow and scrub pines, which were neither so easily attacked as the former nor so resistant as the latter. A carefully arranged table was made out by the forester, showing in exactly what order the various species of trees were arranged as regards resistance to smelter fumes, but the above examples are sufficient for the present discussion. It might also be mentioned that individuals of certain species seemed to possess a certain immunity to the fumes and would grow some times within the area where it seemed impossible they could do so, but in the great majority of cases the divisions between the various species were perfectly apparent to a trained eye.

Having observed how far damage extended in the various directions from the smelters of Ducktown, samples were taken to prove or disprove that this injury was due to the sulphur dioxide given off. For this purpose, samples of the dead and injured trees surrounding the smelter were examined, as well as the uninjured trees of the same species beyond the range of apparent injury by the fumes. The sulphur trioxide content of the dead and injured trees was then compared with that of uninjured trees of the same species situated beyond the seeming area of damage. The soils of the injured trees were of course compared with those of the uninjured trees beyond the limit of damage to show that any increase that might arise in the sulphur trioxide content of the injured trees could not be due to an increased amount of sulphur trioxide in the soil.

If the sulphur trioxide content of the uninjured trees situated much farther away from the smelter, is less than that of the injured trees situated near the smelter, and yet the sulphur trioxide content of the soils in which the trees grow is the same, or nearly the same, in both cases, then this increase of sulphur trioxide in the injured tree must have been absorbed from the air. If the sulphur dioxide was so absorbed from the air, it must have been that which killed the trees, or at least helped to kill them, since we know that small amounts of sulphur di- and trioxide, when absorbed by the leaves of trees, kills them. In the absence of insect pests in sufficient numbers to cause great injury, of forest fires, and other or-

dinary causes for the death of trees, we can only draw the conclusion that it was the sulphur dioxide only that killed them.

Attention should be here called to the fact that this method of comparing injured trees and uninjured trees is much better and more conclusive than the method followed by the writer at Redding, Cal., and should undoubtedly be followed in all cases where such comparison is possible. The country around Ducktown easily lent itself to carrying out the investigation in this way, while in the country around Redding, California, such a method of working out the problem was practically impossible. Of 49 such comparisons, in 46 cases or 94 per cent of the cases examined, the sulphur trioxide content of the injured trees was larger than that of the uninjured trees, at a greater distance beyond the range of seemingly significant damage.

In 82 per cent of the cases examined the sulphur trioxide content of the ash of the injured trees was larger than the sulphur trioxide content of the uninjured trees situated beyond the range of seeming damage.

Dividing these trees into 4 groups according to their direction from the smelter we have the following results.

In a northerly direction in 100 per cent of the cases examined the leaves of the injured trees contain a larger percentage of sulphur trioxide than the leaves of the uninjured trees, and in 81 per cent of the cases examined the ash of such injured trees contains a larger percentage of sulphur trioxide than the ash of the uninjured trees.

In an easterly direction in 100 per cent. of the cases examined the leaves of the injured trees contain a larger percentage of sulphur trioxide than the leaves of the uninjured trees, and in 75 per cent. of the cases examined the ash of such injured trees contains a larger percentage of sulphur trioxide than the ash of uninjured trees.

In a southerly direction in 77 per cent of the cases examined, the leaves of the injured trees contain a larger percentage of sulphur trioxide than the leaves of the uninjured trees, and in 69 per cent of the cases examined the ash of such injured trees contains a larger percentage of sulphur trioxide than the ash of uninjured trees.

In a westerly direction in 100 per cent of the cases examined both the leaves and the ash of the injured trees contain a larger percentage of sulphur trioxide than the leaves of the uninjured trees.

From the above investigation in the vicinity of Ducktown, I would draw the following conclusions in regard to the distribution of injury by the smelter fumes:

1st. That the vegetation around the smelter appears from actual chemical analysis to be injured for at least 10½ to 11 miles north of Ducktown, 8 miles south, 5 to 5½ miles east and 8½ miles west, (down the Ocoee River).

2nd. That there can be but little doubt that the injury extends beyond the limits mentioned in (1), but it cannot be shown by chemical analysis since the difference in sulphur trioxide content between injured and uninjured trees becomes so small as to be within the limits of experimental error.

Investigation in the Vicinity of Anaconda, Mont. A third extremely important study of injury to vegetation and animals by smelter wastes is now being carried on by the writer in the country surrounding Anaconda, Montana. Here the huge smelter of the Amalgamated Copper Co. is situated, roasting, when running at full head, about 10,000 tones of ore per day. This ore is said to contain quite large quantities of arsenic. This smelter is situated in a semi-arid country, where irrigation is practised, the smelter discharging its wastes into certain of the streams that are used for irrigation purposes. There are therefore 3 distinct problems to be worked out in connection with the injury by the smelter.

1st. Whether or not the vegetation is injured by reason of the sulphur dioxide set free.

2nd. Whether or not enough arsenic is set free to settle on the surrounding vegetation and poison the forage plants so that they are unfit for cattle.

3d. Whether the waste when discharged into the irrigation streams, renders the water unfit for irrigation purposes.

The writer has started a study of all of these problems and has obtained enough data to draw tentative conclusions, but the work is still going on, and final results cannot be reported till later.

A few words of introduction are necessary in regard to the situation of the smelter, the appearance of the surrounding country and the injury claimed by the farming community in the vicinity of the smelter.

The smelter is situated on a high hill toward the southern end of Deer Lodge Valley, which is about 35 miles long and 4 to 6 miles wide. It is nearly at the junction of Deer Lodge Valley and Hot Springs Creek Valley. To the north, south, east and west of this valley are quite high ridges of mountains which are cleft here and there by the valleys of small creeks, Hot Springs Valley being one of the largest ones. Down the center of the Deer Lodge Valley runs Deer Lodge River into which are carried the tailings from the smelter. As I have said before, this river is used for irrigation purposes, although a large number of the farmers say that it is injurious and prefer to get their water from small creeks coming down from the mountains on either side, and only use the Deer Lodge River when it is absolutely necessary. The country immediately surrounding the smelter and in the Deer Lodge Valley proper, has never been wooded at all. It is only when we get toward the tops of the ridges and along the valleys of the various small streams and beyond the ridges

that the land is forested to any extent. Besides this, forest fires have swept over certain of the mountains in the past, so that all dead timber cannot be ascribed to sulphur dioxide from the smelter. However, enough trees are present within a radius of 10 to 15 miles from the smelter, which have not been injured in any way by the forest fires, crowding, insect pests, etc., to be able to judge what the extent of the damage by sulphur dioxide has been and is. The three principal species of trees in the neighborhood of the smelter are the Lodge Pole pines, Junipers, and Red Firs. The difference in their resistance to sulphur dioxide fumes is very marked and can easily be observed by any one who chooses to drive over the country.

Trips were made by the writer and a forester for about 20 miles north, 10 miles south, 15 miles west and 6 miles east. Immediately surrounding the smelter practically all trees are either dead or severely injured. A very few trees still stand, to which those who do not believe in the injurious effects of smelter fumes point with pride as being examples of the fact that sulphur dioxide does not injure vegetation. Since, however, hundreds of the same kind of trees are killed outright at 10 times the distance away of these uninjured trees, the force of the argument is entirely lost and the uninjured trees only appear to a disinterested party as curious examples of individual resistance.

On the whole a careful examination shows that the forests are evidently injured for at least 14 miles north, an indefinite distance east, 8 miles south and 13 to 15 miles west (up Warm Springs Creek). The injury to Lodge Pole pines does not extend this far but the injury to Red Firs evidently does. Samples of injured foliage near the smelter and of uninjured foliage beyond the range of seeming smoke damage were collected just as in the case of the Ducktown region. The results of this work are not yet completed, but 12 comparisons have been made of injured samples collected in a southerly and westerly direction from the smelter with samples of the same species of trees collected beyond the range of seeming smoke injury. In eleven of these cases or 92 per cent the injured leaves contained more sulphur trioxide than the uninjured ones.

The next claim made by the farmers and requiring investigation, is that enough arsenic is given off from the stacks of the smelter to settle on the surrounding forage crops and so poison the cattle. To prove this it is first necessary to show that the ores smelted at this smelter contain arsenic. Examinations of three samples of ore, taken personally from three different mines which partly supply the smelter, were made and the following amounts of arsenic obtained: 0.51 per cent; 1.17 per cent; and 2.54 per cent. Of course a large amount of this is condensed by the condensing flues used at the smelter, however a larger or smaller quantity undoubtedly escapes from the chimney. It is next necessary to show that the escaping

arsenic settles on the surrounding forage crops in large enough amounts to be injurious to cattle. For this purpose about 20 samples of range grass and such cultivated crops as alfalfa were collected for distances varying from 1 to 10 miles from the smelter in various directions, but more especially down the Deer Lodge Valley. Ten of these examinations have been made and the results given below obtained. The arsenic was determined by first destroying the organic matter with arsenic free nitric and sulphuric acids and then determining the arsenic by means of arsenic mirrors, using a modification of the Sanger method. [1]

Arsenic Content of Forage.

Description of Samples.					Mgs. of As. per. g. of dry sample.
Bunch Grass	2 miles	N.	Smelter		0.078
Alfalfa	2½ "	"	"	Supposed to have killed cattle	0.052
Pasture "	3 "	"	"		0.052
Red Top "	4 "	N. E.	"		0.021
" " "	5 "	N. E.	"	Supposed to have killed cattle	0.042
Alfalfa	10 "	N. E.	"		0.053
Bunch Grass	3 "	E.	"		0.032
Field "	6 "	E.	"	Supposed to have killed cattle	0.042
Hay	6 "	E.	"	" " " " "	0.031
Bunch Grass	6½ "	W.	"		0.042

From the above table it will be noted that arsenic was found in considerable quantities in every sample examined. Calculating this arsenic to a ration of 20 pounds of the dry forage we find in the case of the forage containing the least arsenic it amounts to about 3 grains per day, while in the case of the forage containing the largest quantity of arsenic it amounts to about 10.9 grains per day. It may be seen from the above that in order that the cattle in this region live at all they must become confirmed arsenic eaters, in much the same way as the mountaineers of Switzerland. Through the courtesy of Dr. D. E. Salmon, the writer was able to examine sections and gross specimens of the viscera of a number of cattle that were suspected of having been killed by eating forage containing arsenic as above. It was noted that the gastro intestinal tract was inflamed and the glands of the stomach and the kidney on section showed desquamation of epithelium, cloudy swelling and in some cases fatty degeneration. The symptoms described by the farmers include inflamation of the mucous membrane of the upper air passages, running from the nose, and incoordination of gait. From the above symptoms and post mortem appearances together with the amount of arsenic found in the various forage plants, there can be but little doubt that the cattle were killed by arsenic.

The third point claimed by the farmers and needing investigation, was

[1] A description of the apparatus used is given in Bull. 86, Bur. Chem., U. S. D pt. of Agr.

the injurious effect of the Deer Lodge River Water on farm crops when used for irrigation. It is evident from an inspection of the Deer Lodge River that tremendous quantities of waste matter from the plant finds its way into the stream. It is also evident from the method of operation that these waste products must contain some copper. This copper is to a large extent in the form of finely divided copper sulphide, which we know in nature forms soluble copper sulphate by gradual oxidation. We would therefore expect that if this material were put on the land it would gradually oxidize to a soluble form in which condition even very minute quantities of it would be more or less injurious to vegetation. It has been urged that even if soluble copper were formed in the Deer Lodge River or subsequently on the land it would be immediately rendered insoluble again by the action of carbonates and bicarbonates present in the water and soil. On the surface this looks plausible, but Skinner[1] has shown that such is not the case, but that when soluble copper salts are brought in contact with solutions containing carbonates and bicarbonates enough copper still remains in solution to be toxic to plants.

Samples of the waste water, from the plant, from the Deer Lodge River just after the waste was emptied into it, and from the Deer Lodge River at various distances from the point of inlet of the waste, were taken and the insoluble and soluble copper determined.

The following results were obtained:

Copper Content of Water Samples

Description of Samples	Insoluble Copper parts per million	Soluble Copper parts per million
Waste water of smelter	31.0	0.05
Deer Lodge River, 1½ miles below entrance of smelter waste	12.1	0.77
Deer Lodge River 6 miles below entrance of smelter waste	12.0	0.15
Deer Lodge River 8 miles below entrance of smelter waste	6.4	0.22
Deer Lodge River at Deer Lodge, about 16-18 miles below entrance of smelter waste	3.1	0.51

It is evident from the above that the plant discharges large quantities of copper into the Deer Lodge River and that even at a distance of 16 to 18 miles below the point where the tailings are discharged, a considerable quantity of copper is still present. Since it has been proven by Heald[2] that seedlings of Pisum Sativum are killed when the solution contains 1 part of copper in 404,423 parts of water and that Zea Mais seedlings are killed in a solution containing 1 part of copper per 808,846 parts of water; since it has further been proven by other investigations that even smaller quantities of soluble copper than the above are injurious to plant life; it would appear that the Deer Lodge River water even at a distance of 16 to 18 miles below where the tailings are discharged, is not fit for

[1] Copper Salts in Irrigation Waters. This Journal 27, (1906).
[2] Botan. Gaz. 22, 142.

irrigation purposes, and will eventually if not at once seriously injure land to which it is applied.

To further prove that land irrigated by the Deer Lodge River contains excessive amounts of copper, samples were taken at various distances from the smelter with the idea of determining in them both soluble and insoluble copper. Several of these have been examined but the results show such excessive amounts of copper that the writer is not willing to publish the results until he has confirmed them by collecting and examining new samples. That considerable quantities of copper are present in this soil, however, is undoubtedly true since the soil along the edges of the irrigation ditches, 12 miles and more below the inlet of the smelter waste into the river, is colored distinctly blue with copper. Further than this, the writer tested the soil on a farm irrigated by the Deer Lodge River water 10 to 12 miles below the inlet of the tailings, with his knife blade and was able to obtain an excellent coat of what afterwards on examination proved to be copper.

Although the results of the examination of the injury to vegetation and animals by the Anaconda Smelter is not completed, from the work already done the following definite conclusions can be drawn.

1st. The vegetation around the smelter for at least 7 to 8 miles south and 13 to 15 miles west is seriously injured.

2nd. The Junipers are very resistant to smelter fumes and appear able to grow close to the smelter; the Red Firs are very susceptible to the fumes and are badly damaged at distances of 13 to 15 miles from the smelter; Lodge Pole pines are intermediate between the other two species of trees, but show damage for at least 10 miles.

3rd. Large quantities of arsenic are discharged from the smelter on the surrounding country, being present in forage crops in large enough quantities to poison cattle.

4th. The waste from the reduction plant discharged in the Deer Lodge River renders it unfit for irrigation purposes.

A PORTABLE PHOTOMETER.

By James A. Evans.

Received May 11, 1907.

During the years 1901 and 1902 the writer was Gas Inspector for the city of Cleveland, Ohio. During that time it became very urgent to know in concrete numbers what candle power the street lamps were producing, because the contract for street lighting was given on the basis of a definite candle power, with a penalty for falling below the specified standard.

The lamps were mantle burners with glass chimneys and enclosed in glass globes. They were fed by artificial gas and by gasoline. We