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Second Edition.—Revised and Enlarged.

ON THE

PRESENCE OF ARSENIC

IN THE

VAPOURS OF BONE MANURE,

A Contribution to Sanitary Science:

BY

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ADDENDA.

PREFATORY NOTICE TO SECOND EDITION.

THE original edition of my pamphlet, printed for private circulation a few weeks ago, was unexpectedly exhausted within a few days, hence my inability to oblige numerous applicants. In the present issue, which meets the requests of many individuals, I have neither pecuniary interest nor liability. A friend, acting with a public motive, has undertaken the risk, and I hope that he will be recouped for his outlay.

Much public attention has been given to my statements, and no competent attempt has been made to controvert any matter of fact. On the contrary, I have received numerous corroborations, together with expressions of concurrent opinions, some of which are of a very satisfactory kind. Thus, I quote from the letter of a well-known professional chemist, holding high responsible position. He says that the pamphlet "has set me to think of the matter in a way I "have never done before. We were all aware, of course, that not "only is arsenic to be found in sulphuric acid, but also that in "certain operations in which that acid is employed the arsenic is "converted into volatile and, consequently, highly dangerous com- "pounds; but, somehow, it never occurred to me, at all events in "the way your paper has put the matter before us, that any such "danger could arise from the familiar operation of manure making. "You certainly are entitled to the thanks of the community for your "valuable results." Now, this is the effect I am seeking to produce, viz., to lead intelligent minds to think of a set of facts and conditions "in a way they have never done before," and I commend very strongly this frame of mind to all manufacturers who use sulphuric acid largely. I am glad to know that in some instances my communication has been studied and my suggestions accepted with the good feeling in which they are offered. One manure manufacturer informs me that he has already arranged, at a cost of several hundred pounds, "to put his house in order," rather than wait for the compulsory provisions which are likely to follow the recommendations of the Government Commission on Noxious Vapours, now sitting. Other manufacturers tell me that they are taking into consideration the hypothesis which has been naturally suggested, viz., that dangerous conditions, similar to those which I have demonstrated to exist in the making of artificial manures, may attach also to other branches of trade employing sulphuric acid in large quantity. Some individuals have assured me that they have got materially useful information regarding the quantities of arsenic which I have shewn to be contained in the chief kinds of pyrites from which sulphuric acid is made, and particularly valuable information regarding the actual amount of arsenic which is found in different qualities of acid manufactured, a point on which there is at present no other source to which reference can be made. They have also found usefully suggestive the details which I have given of the varied forms and conditions under which arsenic may be volatilised and passed into the atmosphere. All this is gratifying to me, and compensates for the angry comments which have emanated from other interested but almost wilfully ignorant persons.

I have been asked for "the remedy." Already, in several references, as in that to the Alkali Act, I have stated that a thoroughly efficient remedy may be had. But it would be a great mistake for me to lay down in detail the various conditions which have approved themselves to my mind as sufficient to prevent manure works from being reasonably charged for nuisance. These details must vary with individual cases, and manufacturers must have their convictions ripened before they can cheerfully adopt effective remedies. In the first few pages of my "Report on a Manure Work," I have indicated necessary principles of construction and arrangement, when pointing out a sufficient number of those faulty conditions which gave rise to the nuisance, and which should therefore be avoided. In this case, no patchwork or makeshift expedients will suffice, and a costly reconstruction is inevitable, notwithstanding all statements of unscrupulous law agents to the contrary. There is little difficulty in planning *new works* with buildings and with sanitary appliances that will prevent the diffusion, and sufficiently condense, mitigate, or practically destroy all the offensive vapours I have particularised. The real difficulty is how to alter the construction and modify the processes of existing works. In the meantime, I will only say that this difficulty is not insurmountable, and has, to my knowledge, been in great measure overcome, even under very unpromising circumstances.

From that side which most affects the popular feeling, it has been urged against my argument that it is essentially defective, because that I have not brought forward instances of illness and of death caused, beyond all possible question, by vapours of manure works. But this is not my present undertaking. Nothing can be more explicit than my declaration that, on the threshold of what is a new enquiry, having a wide range and many corners, and relating to a manufacture of recent origin, I have restricted my investigation to what one individual may be reasonably expected to accomplish. It is for a Government Commission to attempt more. I have proved that "there is an occupation wherein neither the workman employed nor the people who live within the range of his operations have been hitherto made aware that they are liable to breathe, and actually do breathe, an atmosphere contaminated with the deadly poison of arsenic, and this in addition to the risks of an atmosphere already made impure, offensive, and unwholesome from other contaminations." I have farther pointed out why it is that instances of illness or of death escape recognition, from being in their nature insidious and obscure, difficult at all times to demonstrate, and dangerous at all times to suggest. If future enquirers will bear in mind the facts I have set forth, and will endeavour to think of the subject "in a way they have never done before," and if the enquiry is made with the powers and under the protection of a Government Commission, I predict that those who have asked for signs will be abundantly satisfied. Meanwhile, I suggest that individuals of competent scientific skill, having free access to such works, may do good service through chemical *and physiological* investigations conducted at the works in an honest spirit of enquiry that has truth alone for its object.

I have carefully revised the text, interpolated some additional matter, constructed a table shewing the quantity of arsenic likely to be contained in sulphuric acid made from the principal commercial pyrites, and added a few supplementary notes, the most important of which consists in a letter from Mr. Lawes, "the father of the chemical manure trade," and in every sense the most authoritative and most competent commentator that could illustrate the question I have discussed.

JAMES ADAMS.

November, 1876.

PART I.

ON A MANURE WORK.*

At the recent trial in the Court of Session of a case of "Nuisance," viz.: Fraser *v.* Cran, I gave evidence, in the course of which I advanced certain novel facts relating to the presence of Arsenic, which I alleged to exist in vapours disengaged during the manufacture of Bone Manure. The case possessed features of unusual importance, because that the sudden illness, ending in the sudden death, of the original prosecutor was held to have been directly caused by the nuisance in question, a view adopted by the Court in its decision. That portion of my evidence which relates to arsenic had a special bearing on this view. But it was only incidentally referred to, and was not pressed by the prosecution, for reasons to which I will afterwards refer. The case has excited considerable interest, and is unquestionably one of public importance, not only in a sanitary point of view, but also in its bearings upon manufacturing industry. This will be readily recognised from the following short statement of the circumstances which preceded the trial.

On Monday, 21st February, 1876, John Fraser, Esq., of Bunchrew, left his family seat at Bunchrew to proceed by railway to Inverness, a distance of 3½ miles. As he was passing into the station, a small roadside stopping place, he encountered a volume of offensively smelling vapour, that was suddenly disengaged from a Bone Manure Work, which practically forms a part of the station. Mr. Fraser immediately became sick and faint, and was at his request placed by the station-master in an empty compartment of a railway carriage. He hung his head over the window and continued vomiting until he reached Inverness. He was there conveyed to the Station Hotel, and Dr. Mackay, Medical Officer of Health, and Dr. Wilson, an eminent consulting physician of Inverness, continued in attendance upon him until his death on Thursday following. Next day his body was removed to the family mansion, which he had so lately left in the enjoyment of a state of health so perfect, that within the recollection of his family he had never ailed for a single day. The

* Read before the Glasgow Medico-Chirurgical Society, April 21, 1876.

symptoms observed by his medical attendants were continuous pains of stomach, continuous bilious vomiting, and great prostration. On the third day the pains and sickness abated somewhat, and on the fourth, feeling a little stronger or relieved, he attempted to rise, fainted away while seated on a chair, and there died. His medical attendants were unable to recognise symptoms of any known disease, and could not certify any—they were satisfied that he was of extraordinary sound and vigorous constitution, and free of organic disease —and they could not account for his death as proceeding from any other cause than that which he himself had assigned as the immediate and the exclusive cause of his illness.

Mr. Fraser had, with his family, already experienced that the Bone Manure Work was a serious nuisance, and had raised an action to interdict its operations. The action was instituted for the 2nd March, but Mr. Fraser's death on the 24th February caused a postponement. His Trustees, immediately after his death, took up the litigation, which was disposed of in the Court of Session on March 24th, before Lord Shand, after a proof which lasted over four days. His Lordship found clearly for the prosecution, and interdicted the work. He made a touching allusion to Mr. Fraser's death, as a remarkable and painful feature in the case, and said that, "Having regard to the "general evidence, as well as the evidence having special reference "to the late Mr. Fraser's last illness, I see no reason to doubt the "truth of the conviction which Mr. Fraser, the members of his "family, and the doctors who attended him, formed as to his illness "having originated in the way already stated."

It is something remarkable that several weeks before this sad event, I had communicated to Mr. Fraser's agents that I had made a discovery of a dangerous set of conditions, belonging to the manufacture of Bone Manure. I had also mentioned to several professional friends my conviction of the possibility of such an occurrence as actually did take place in the case of Mr. Fraser, and I had drafted that portion of my report which embodies my experience and my convictions. I was therefore not greatly surprised, although much grieved and shocked, when, unaware of Mr. Fraser's death, owing to the over late delivery of a telegram, I chanced to reach the Station Hotel, Inverness, at the moment his body was being conveyed to the family residence. The details then given to me by Mr. Fraser, Jun., and his Solicitor, of the nature and order of the symptoms which characterised the illness of the deceased, satisfied me that a combination of the conditions I had stated to be possible had actually occurred.

It is the object of the present memoir to show the nature of some of these conditions, and for the special reasons I commence my observations by reproducing the revised draft of the Report which I prepared for the use of Counsel.

62 Cambridge Street,
Glasgow, *13th March*, 1876.

On 25th February ult., and on 11th March inst., I visited the Northern Counties Bone Manure Works, situated at Bunchrew, Inverness, with the special object of ascertaining how far the manufactures carried on at said works were likely to affect the comfort and health of individuals residing in their vicinity, and particularly the health and comfort of individuals dwelling on the property of the late John Fraser, Esq., of Bunchrew.

The facts I have noted, and the conclusions at which I have arrived, will be best understood by dealing with them in the following order, viz.:—

1. A short description of the processes of manufacture referred to.
2. The probable effect of said operations on the comfort and health of the neighbouring population.
3. The conditions of locality which have a special bearing on the question under consideration.

The operations at the works consist essentially of three stages, viz.:—the storing of raw material; the manufacturing processes to which the raw material is subjected; and the storing of the manufactured article.

That part of the stored raw material which merits chief notice consists of bones of animals in a more or less fresh condition. These bones, besides their mineral constituents, contain various organic matters—as flesh, tendon, fat, gelatine, and other soft parts of the animal. As stored they are always in a state of decay. Noxious gases, some of repulsive odour, together with organic emanations of unknown chemical composition, are continuously disengaged, and are capable of infecting the atmosphere in the absence of preventive measures. The construction and arrangement of a bone store is therefore a matter of much importance in a sanitary point of view, and with special reference to individuals residing in its vicinity.

The first stage of the manufacture of bone manure consists in crushing the bones by machinery, and a large amount is not subjected to any other operation than is necessary to reduce the fragments to the condition of 'bone meal.' During this process the 'meal,' in a state of fine powder, floats about the premises, and, if suitable precautions are not taken, may be wafted outside so as to be perceived in an offensive degree at long distances from the work.

But by far the greater portion of the bones is subjected to a second stage of manufacture, which is technically termed the 'mixing process,' and it gives rise to a very different and more important set of conditions. The crushed bones are placed in an iron mixing-box, and impure or commercial sulphuric acid is poured upon the mass, which is agitated by the mixing apparatus until converted into a porridgy consistence. It is then run out of the mixing-box and falls upon the floor of the mixing-room. A powerful chemical action takes place in the mixture—great heat is developed, and large volumes of dense watery vapours are disengaged. The mixed material, often before it has cooled, is shovelled into wheelbarrows and conveyed to one of the sheds and left to dry. For several months it continues to undergo active chemical action and to evolve gaseous vapours. To insure that the mass is uniform, and also to hasten the cooling and drying process, it is occasionally turned over, the lumps broken and passed through a coarse sieve, &c. Chemical agents, which are technically called 'driers,' are also used at this stage, and their use materially aggravates any nuisance which may be caused, by causing for several days after their use a more active disengagement of vapours. The vapour, which meanwhile is being continuously disengaged, is heavily loaded with various offensively-smelling and irritating gases, with volatile acids and with vapours from decomposing animal matter. *It is also loaded with a considerable quantity of the deadly poison—arsenic!* This important fact has, so far as I can learn, not previously been made the subject of comment. It presents a much likelier cause of injury than the so-much dreaded use of wall-papers coloured with arsenical green, and I have thought it advisable to enter a little more fully into the subject in an appendix to this report.

In considering the probable effects of the manufacturing processes thus summarised, it must be borne in mind that, beginning with the first stage, viz., the storing of heaps of decaying bones, there is no essential difference between these bones and an accumulation of decaying human bones.* Any offence to the senses or injury to health

* Referring to this statement, Dr. Angus Smith writes to me—"That is an "interesting and very important point *scientifically*. Is human decomposition "more offensive than common animal decomposition? I could not prove it, "but I am inclined to think it is. It is very peculiar, just as one may say the "peculiarities of pig, sheep, game, and so on; but the senses abhor it, more "perhaps from fancy—who can tell? I once had a speculation, and I think I "published it, that the higher organizations are connected with more compli-"cated physiological or chemical compounds, and these to more activity in the "products of decay. I think it probable, and it would explain the opinions of "men on the subject. It would also demand that the most highly organized "races should be most offensive in their decay."

Everything that proceeds from Dr. Smith in relation to atmospheric contamination deserves a consideration almost amounting to deference. The speculation referred to is very suggestive, and at first sight very captivating, for it is certainly true that we are instinctively revolted by the sight and odour of decaying human beings. Moreover, our *amour propre* is flattered by the suggestion that man, although an animal, is still "the paragon of animals." A mere chemical analysis of the actual composition of man contrasted with that of animals, will not throw light on this problem, neither, I suspect will a chemical analysis of the products of decomposition. Nevertheless, the chemical interactions of the animal economy cause sensible differences, as is shown in contrasting the odour proceeding from the live pig, which differs from that of the sheep, and the same is observed of their excreta. There is a marked difference which can arise from one is equally likely to proceed from the other. According to my experience in connection with the judicial closing of overcrowded graveyards, a very serious view is taken, and ought to be taken, of such a state of things. I believe that the most overcrowded and ill-managed churchyard is not capable of causing the offence and the injury which may be occasioned by a large and ill-conducted bone store.

Nearly all the various components of the vapour given off in the mixing process are naturally heavier than atmospheric air. All have a natural disposition to attract and to be absorbed by water. They are disengaged in immediate association with water, and the heavy vapour thus compounded has no natural tendency to mount upwards. Its tendency, on the contrary, is downwards, and it flows heavily. It spreads or diffuses in the direction of air currents, until no longer recognisable by reason of absorption into the ground, and dilution in the atmosphere.

All the gases of known composition contained in the vapour are irrespirable, and several—even when considerably diluted—are extremely pungent and corrosive, giving rise to irritation in the eyes, nose, mouth, throat, and air passages. Those derived from arsenic are deadly poisons. But even the least injurious aggravate the danger of existing ailments, and in cases of weak or diseased lungs occasion much immediate distress.

The effluvia from the decomposing animal matter, while under the action of the sulphuric acid, are repulsive to most individuals. In all persons not accustomed, and particularly in impressionable individuals, they produce a peculiarly loathsome, sickening sensation, and can be supported only with difficulty for a few instants.

Irrespective of what can be proved to be positively offensive or positively dangerous in the conditions of a bone manure work, there exists a negative and too little considered cause of danger. There is a certain valuable, but also a very variable constituent of a pure atmosphere—a peculiar condition of oxygen called ozone—which has the remarkable property of destroying effete organic matter in the air. It also wonderfully invigorates the animal economy. As might *a priori* be expected, it abounds in all well-approved places of health resort, and presumably should be present in large quantity in such a locality as Bunchrew. But owing to the enormous amount of dead

in the odour of the Negro and that of the European. The experienced physician recognises a peculiarity in odour characteristic of a Puerperal Fever, or of Typhus, or of Cholera, and so on. Many facts show that chemical action is modified in animal bodies and in different animals. This is however but a very small step to reach such a conclusion as, that man brought within the injurious influence of exhalations proceeding from living or dead men, will be more injuriously affected than when he is brought within the injurious influence of exhalations proceeding from living or dead animals. And this, I suppose, is stating the question which Dr. Smith throws out as a speculation. I am so far in favour of Dr. Smith's view, that I can call up for my own reflection a number of considerations which make for it, but these would lead to a disquisition for which the present place is unsuitable.

animal matter with which the atmosphere surrounding the manure works is loaded, this health-giving constituent of a pure air must necessarily be neutralised and used up in destroying the organic matter referred to. Therefore, the great natural advantages of Bunchrew as a place of residence will, in this regard, be materially deteriorated.

There is consequently offence and danger connected with the vicinage of a bone manure work, and associated with its operations from the first to the last stage of the manufacture.

I have now to consider whether there exists any condition either as regards the locality in which the works are situated, or as regards any special appliances which the factory itself may possess, and which may have a tendency to mitigate—or it may be to aggravate—the disposition to nuisance so far as the mansion-house and properties of the estate of Bunchrew are concerned. And here the first condition which I notice with surprise is, that the factory is planted so as actually form an integral part of the railway station—a very modest and limited roadside stopping-place it is true, and scarcely meriting the name of a station. But I assume that it is outside the scope of my present enquiry to do more than to make a mere reference to this unfortunate relation of the manure factory, which perforce brings all individuals, however impressionable, however apprehensive, within the range of any offensive or injurious influence which may be proved to originate in the works, and I leave discussion of that consideration, although I consider it one of much importance, and having a fair connection with the question in its full bearings.

The factory is situated on a rising ground, which touches the edge of Bunchrew estate. The ground slopes downwards from the work towards Bunchrew mansion-house, situated at the sea-shore, about 600 yards distant. The dwelling-houses of the servants and others employed on the Bunchrew estate are of a superior character, and are situated within a couple of hundred yards of the factory. A line running from south-west to north-east would pass direct from the works and through the Bunchrew cottages and offices, and reach Bunchrew mansion. A wooded ravine and rapid stream of water—the "Bunchrew burn"—intersects Bunchrew estate, running from south to north between the works and Bunchrew mansion. The grounds surrounding Bunchrew House are well wooded with full-grown trees.

The first point deserving consideration in this topographical summary is the elevated position of the works in their relation to Bunchrew estate. The vapours discharged during the manufacture of the manures, as I have previously explained, are much heavier than atmospheric air, and not only have no tendency to ascend, but have, on the contrary, a downward tendency. In still weather these vapours will therefore naturally gravitate and flow towards and over the properties and mansion of Bunchrew, and this natural tendency will receive an increase from the directing current of air which naturally follows the course of the ravine and stream referred to. The fact of the relatively greater elevation of the works above Bunchrew estate is therefore an unfortunate aggravation of any nuisance which may be occasioned by the works.

But when there is wind the vapours will travel with the wind, and it is therefore of the highest possible moment that it should be ascertained—*First*, the directions of the wind which will bring the vapours of the manure works down upon the grounds of Bunchrew; and *second*, the direction of the winds which actually do prevail in the locality. Referring to the first point, I find from careful observation made on the spot, and corroborated by reference to the Ordnance Survey plans, that when the wind is from the south, or west, or south-west, any vapours which may be discharged from the manure works are necessarily wafted down upon the dwellings and property of Bunchrew. But when the wind is from the north, or east, or north-east, such vapours will be diverted from the property. Regarding the actual direction of the winds which do prevail, I have fortunately found a reliable source of information in the returns of daily observations made at the residence of Arthur Forbes, Esq., of Culloden, and published by the Registrar-General for Scotland. The properties of Culloden and of Bunchrew are for meteorological observations strictly one district, and for the present purpose any such observations made at one of the points named are fairly applicable to the other. I have compiled an abstract of these returns extending over the years 1872–73–74, when they terminate. They are complete for 1872, but imperfect for 1873 and 1874. They record the state of the wind for 759 days, viz.:—

For 1872, . . .	366 days.
„ 1873, . . .	150 „
„ 1874, . . .	243 „

Excluding extreme points of the compass, and limiting our regard to the points which directly affect the relation of the manure works to the Bunchrew estate, I have the following result:—

South, . .	170 days.	North, . .	32 days.
West, . .	205 „	East, . .	108 „
South-west,	152 „	North-east, .	32 „
Total, .	527 „	Total, .	172 „

Calm or variable, ... 41 days.

From these returns it is demonstrated that on at least six days out of every eight the wind blows from the manure works over Bunchrew grounds.

It is the character of these prevailing winds to be already so laden with moisture, that they can do little in the way of absorbing any watery vapours which may emanate from the works, and their tendency will be to drive such vapours in full undiluted force down upon Bunchrew grounds.

On calm or variable days any tendency to currents in the air is usually in the direction of the prevailing winds, and on such days, therefore, the offensive vapours referred to will incline to drift and gravitate in a downward flow upon the lower level of Bunchrew property.

Another peculiar condition of the locality tends still farther to aggravate any nuisance arising from vapours wafted by the south and west currents of wind. The factory is itself overtopped by the ground immediately to the south and west, where it rises in a precipitous wooded bank, the beginning of Kinlea Wood, to a considerable elevation above the works.* The result of this configuration of the ground is to dominate the works, and so becalm them that the force of the winds blowing from the works will be abated, and will carry with them in a sluggish current the vapours on to the lower wooded grounds, where they will be retarded by the trees, and their dispersive force still farther diminished. All local influences seem, therefore, to have the tendency to aggravate any nuisance which may proceed from the works.

If the inmates of dwelling-houses on Bunchrew estate should endeavour to mitigate the nuisance by closing the doors and windows, the result will be to make such dwellings close, stuffy, and unpleasant by the offensive vapours which find ingress, by the insufficient removal of bad air, and by the insufficient renewal of fresh air. Indeed, it seems to me highly probable that the dwelling-houses on this property must be always more or less tainted, because the peculiar effluvia of the bone manure works cling very tenaciously to clothing, carpets, blankets, hangings, and napery—as an illustration of which, I carried the odour in my clothing back to Glasgow. Invalids and inmates of sedentary habits are therefore likely to suffer much from the compulsory breathing of infected air which may proceed from the factory.

The injurious influences to which I have referred apply exclusively to individuals exposed. With regard to allegations of injury done to vegetation, I deem it necessary to state that, while it is notoriously true as a general fact that the acid vapours of chlorine and sulphur are very destructive to vegetable life, there is no reliable evidence, according to my observation on the spot, that any hurtful effects have actually been caused to the vegetation of Bunchrew estate.

As I have found nothing in the situation of the factory in relation to its position or its exposure to prevailing winds that can mitigate the nuisance it occasions—having found, in point of fact, that these are *irremediable conditions*—I have sought in the construction and in the appliances of the works for anything that effects or can promise relief.

On entering the factory, which 'marches' with the public road,

* This I ascertained by observation with the aneroid.

and covers a piece of ground about 200 feet in length by 100 in width, it is instantly to be recognised that the few workmen's sheds of which it consists are little better than the extemporised outgrowths of an increasing trade, originally carried on under primitive conditions, and still retaining that character. There is, throughout, no intelligent appreciation of sanitary conditions, and no efficient appliances to protect outsiders from the annoyance of what is so evidently an abominable nuisance to all who are not pecuniarily interested in the factory.

There are no enclosing walls,—not even a gate. It is but a step off the public highway, and the work is entered as freely as its waste products are discharged freely upon the public road and into the open air. There is no systematic connection of parts, and there is the freest possible intercommunication between the various partial compartments and the freest possible communication with the outer air. One of the sheds forms the boundary of the public road. This shed is about 200 feet in length, 9 feet in height, and 12 in width, and seems to be used almost exclusively as a store for the bone meal, and for the completed manure. Excepting the supporting or back wall this shed is constructed entirely of wood. The larger shed is about 150 feet long by 60 feet in depth, and from 12 to 20 feet in height—ridge and hollow. This extra height permits the formation of a loft or upper floor. It is in this larger shed that the chief manufacture of manures is carried on and the stores of raw material kept. The largest proportion of bones lie in the upper flat, and the crushing machinery is fed from this upper, and discharged into the lower flat. A large vitriol tank containing about 15 tons of acid supplies the mixing-box, which is suspended from the roof of an apartment in the lower flat called the mixing-room. The lower floor of the shed consists chiefly of a store for the mixed manure while it is gradually reaching the comparatively dry condition which fits it for sale. But throughout the irregular and partial compartments of the entire large shed the raw material and the manufactured article are stored promiscuously. I could obtain no reliable information regarding the total quantities of raw materials and manufactured manure which were stored on an average, but I estimated that on each occasion of my visits there would be about 300 tons of bones, and about 1000 tons of manure.

The mixing-room is about 12 feet wide and 10 in height. The mixing-box is suspended from the ceiling, and is supplied from above with crushed bones and sulphuric acid. The contents of the box when sufficiently stirred with the mixing apparatus are discharged upon the floor of the mixing-room, and the box is again filled and again discharged, until a total quantity of about 25 tons has been mixed. Meanwhile large moveable wooden shutters are applied so as to enclose the mixing-room, and to prevent the vapours which are being disengaged from escaping into the outer air. A square wooden sided well gives light from the top roof of the building, and a square opening in the first ceiling of the mixing-room is continued upwards into a wooden pipe leading to a recent addition to the works, called a coke tower.

The object of a coke tower is to condense volatile vapours which are capable of being absorbed by water, and the intention of the so-called coke tower now under consideration is that of condensing the vapours which proceed from the heaps of dissolving bones lying on the floor of the mixing-room. This tower is a brick erection about 15 feet high, and about 5 feet by 8 feet in outside diameter. It is divided vertically inside, and is packed with coke from coal. A wooden lid covers it at top; a pipe ending in a rose is led from the engine-boiler* to the top of the tower inside, and when in action this pipe sprinkles water in the manner of a shower bath upon the coke, and the water trickles downwards through the coke and flows from the bottom of one side of the tower into a discharge-pipe which empties into the open roadside gutter at a distance of about 40 feet from the tower. Another pipe emerges from the bottom of the other side of the tower, and is led about 20 feet to a close proximity with the engine-furnace, where it opens on a level with the ground, and at fitful intervals a sheet-iron pipe is inserted into the opening. At the same time the blower of the furnace is attached, and the other end of the sheet-iron pipe is adjusted to an opening in the blower. The mixing-room and coke tower are situated about 60 feet apart, and a communication is formed between them by means of a wooden pipe about 8 inches inside diameter, which, rising from the first ceiling of the mixing-room, ascends through the roof to the outside of the building, and passing *in a horizontal line* a considerable distance descends to the ground, is again continued in a horizontal line until it finally enters the bottom of one side of the coke tower. It is this long tortuous passage which the heavy vapours disengaged in the mixing-room are intended to traverse, drawn by the aspirating force of the furnace. As they pass up one side of the coke tower and down the other, through the obstruction of the coke and descending shower of water, they are intended to be absorbed and dissolved in the water, and emptied into the roadside gutter, while such portions as are not capable of being absorbed by water are to be carried through the furnace, decomposed, and the waste product discharged up the chimney-stalk. It is at once obvious that only by an enormous furnace could the heavy vapours be drawn along a passage characterised by so many mechanical difficulties; and these difficulties are further magnified by mechanical imperfections in the arrangements, such as certain breaks in the continuity of the long tubular communication. The supply of water for the coke tower is derived from the engine-boiler—a very evidently insufficient supply *as the effective action of a coke tower depends altogether upon an abundant*

* This description of the mechanical connections of the water supply was given to me by the foreman, or superior workman, who showed me over the premises.

and a continuous descending stream. According to my information that abundant stream is not available, the entire supply being obtained from a small well sunk in the hillside at the back of the factory, or from a tiny runlet about 200 yards distant, and this latter source is frequently dried up. It is, therefore only such a sprinkling of water as can be spared from the engine-boiler, and pumped by special arrangements into the tower that this coke tower can receive. I assume that while the water is being withdrawn from the boiler the general machinery of the factory is brought to a stand. Now, when it is borne in mind that for this coke-tower contrivance there is required a series of disconnected operations brought into use only at irregular intervals, and carried out by unskilled labourers, whose natural perceptions are obtunded by familiarity with the nuisance, and who naturally will grudge the time and effort bestowed upon what they consider an unnecessary refinement, it will appear very probable that these troublesome arrangements and disarrangements will rarely be attempted. And, in point of fact, I obtained a convincing proof of the correctness of my surmise as to the insufficiency of the entire affair.

On the occasion of my second visit, after witnessing the mixing of a considerable quantity of material, I proceeded to the outfall of the coke-tower discharge-pipe into the roadside gutter, and I repeatedly tasted the water as it was discharged, presumably saturated with the acrid, offensive, and acid emanations of the mixing-room. I found the water clear and insipid, *with not the slightest taint of acidity or offensiveness* such as I know characterises, and must characterise, the outflow of a properly acting coke-tower. I then proceeded to test the action of the pipe which discharges the vapours into the furnace. This vapour was presumably washed free of all visible and soluble matter, and its presence in the pipe, and its passage into the furnace, should no more have been perceptible than a current of invisible air. I found, on the contrary, the *dense acid vapours presenting visibly the same appearance* as when disengaged in the mixing-room, and I lifted out handfuls of the vapour, and smelled it and tasted it, with the result of satisfying myself that the biting and irritating acid vapour had undergone no recognisable change. At this time I left the works, and with other gentlemen who joined me in the inspection, proceeded to Bunchrew grounds. But surmising that the intense furnace action I had seen produced by the closing of the blower and opening of the damper was too costly an operation to be kept up long, I returned within half-an-hour and found the outflow from the coke-tower had quite ceased—that the furnace-blower was removed—the connecting pipe had disappeared, and the opening into the vapour-pipe was covered over. Meanwhile the white vapours which had previously been observed leaking out from the wooden lid of the tower still continued. The coke-tower was not acting, but the bones in the mixing-room were dissolving.

But although the coke-tower was well planned, the connections perfect, and the supply of water sufficient, there would still be little abatement of a nuisance; for this coke-tower is intended *to operate only upon the vapours of the mixing-room* which are disengaged *at the commencement of a chemical action*, and it has no operation, real or intended, upon the 1000 tons or thereby of manures and other decomposing animal matter which are lying scattered through the entire factory. Neither has it any operation at the frequent periods when the mixing-room is opened, the smoking mass disturbed and carried away in wheelbarrows to be deposited in the various store-sheds. Neither has it any action throughout the night, when the furnace is blown out, and the factory operations have ceased. Considered in every point of view, it would be difficult to carry out the conception of a coke-tower in a more insufficient manner. So far as its effects on the nuisance of this bone factory is concerned, the operations of the work might as well be carried on *pleno cœlo* in the manner of a gipsy's camp-kettle.

Speaking generally, my experience of the practical operation of a coke-tower *in connection with a manure work* has not been favourable. I have not seen or heard of a successful example, and, on the contrary, have had the chagrin of seeing one standing inoperative, which had been erected under my own advice, corroborated by that of several eminent authorities. It was one of the make-shift expedients that are the occasional abortive outcome of public complaint—tedious costly litigation, and a judicial order. The causes of disarrangement and of imperfect working of coke-towers, when applied to manure works, are very numerous; and it is my belief that the chief purpose they serve is that of the proprietor, by acting as a gag or blind on the public.

It is alleged that the gaseous, offensive, and waste products of the work are more or less carried off ultimately by the chimney-stalk, but there is no ground for such a statement, if I except what occurs during the partial action and fitful periods when the tube from the mixing-room is connected with the furnace. If, however, there did exist all the necessary special arrangements for collecting and directing all the offensive effluvia, &c., into the chimney, and so discharging them into the air, there could result no real abatement of the nuisance as it affects Bunchrew property. The chief effect would be to sweeten the work, and to carry the nuisance past its own door.

I made another visit on the evening of the 11th March, and, as on the two previous occasions, thoroughly satisfied myself that the offensive emanations of the works were present in an offensive degree in the vicinity.

On a careful consideration of the facts referred to in the foregoing report, I am clearly of opinion that:—

I. The operations of a Bone Manure Work are in their nature likely to be productive of a serious nuisance.

II. The situation of the Northern Counties Bone Manure Factory, with special reference to Bunchrew estate, and its position in relation to the prevailing winds of the locality, are irremediable aggravations of the nuisance such a work is capable of causing to the Bunchrew estate.

III. The works in question are, as a whole, constructed with no intelligent appreciation of sanitary conditions; are possessed of no sufficient contrivances for preventing or abating a nuisance; and are therefore practically productive of all the offence, the probable injury to health, and the danger to life, of which such works are capable.

IV. The amount of offensiveness occasioned by this work is a real and serious inconvenience, and a substantial interference with the comfort of life of individuals residing on Bunchrew estate.

JAMES ADAMS, M.D.

APPENDIX TO REPORT ON A MANURE WORK.

Chemical gases and animal poisons distinguished—Bad smells not the real sources of danger—Discovery of arsenic as an invariable constituent of the vapours produced in Bone Manure manufacture—Illustration of hurtful effects of Bone Manure Factories, &c.

Gaseous exhalations from decomposing animal matter are all more or less irrespirable or poisonous. When concentrated they act with immediate injurious effect upon health and life. Of some the composition is known to the chemist, their presence can be detected by chemical process, and their hurtful effects can be predicated by the physician. These may be termed the chemical gases, and it is of much moment that in an enquiry such as the present there should be a clear recognition of the distinction that exists in the mind of the physician between chemical gases of known composition and animal miasms of unknown composition.

The chemical gases from decomposing animal matter, of which carbonic acid and sulphide of ammonium are examples, may not only cause a nuisance, but they may kill. They may kill by poisoning speedily or within a few hours, or after some days, according to the strength of the dose, its concentration, or the vigour of the individual. But if a fatal dose has not been imbibed the sufferer will begin to recover as soon as he is removed from continued exposure, and whatever his sufferings these cannot be communicated to another person. Of nuisance, and of injury, and of death arising from exposure to the effects of chemical gases, I might furnish many illustrations. At present I desire special attention to a very probable and hitherto unsuspected cause of danger arising from chemical gases generated during the processes of Bone Manure manufacture.

The offensive-smelling gases and irritating volatile acids, which are disengaged under the chemical action of sulphuric acid upon crushed bones, are on the whole pretty well known. They are all, so far as known, possessed of qualities which are chiefly remarkable, in a sanitary point of view, for their property of causing immediate discomfort and of aggravating already existing disease. But as far as I can learn, the presence of the deadly poison of arsenic amid these gases has not hitherto been the subject of special observation or special enquiry. And yet there is no doubt whatever of the fact, as I have now demonstrated, through careful, frequent, repeated, and altogether exhaustive experiments, some of which have been made with special reference to the present enquiry. This is therefore to be considered practically as a discovery of a hitherto unknown and unsuspected set of conditions. I had for a considerable period held strong suspicions almost amounting to conviction on the subject. I had suspected that I had obtained the clue to the real cause of mysterious illness and of actual death occurring among individuals exposed to the noxious emanations of Bone Manure Works. The symptoms in these cases were not such as I could reasonably refer to any well known form of disease, but they were such as could arise from the inhalation of arsenical vapours. Having had occasion, some years back, to study the literature of arsenical poisoning, while preparing for publication a number of cases that had come under my personal observation, I became impressed with several points of resemblance between the mysterious cases of illness and death referred to and those cases of poisoning by arsenic observed by myself, and regarding the nature of which no doubt existed. And my interest in the subject being revived in connection with the present enquiry, I have now brought the question I had proposed to myself to a positive solution. The facts are so simple and so obvious when explained, that it seems quite marvellous that suspicion and enquiry has not previously been directed to the subject.* The

* Since the above was written, I find that suspicion and enquiry have been directed to works of an allied character. I quote from Dr. Angus Smith's "Air and Rain," 1872, page 468, where, in reference to alkali works, it is stated :—

The muriatic acid is not perfectly pure but contains arsenic, as does the sulphurous. Mr. Henry Arthur Smith—also see Mem. Lit. and Phil. Soc. of Manchester—has lately found in the acid leading to the condenser from the pans where the salt is decomposed, ·158 grain in 1000 cubic feet, as a mean of twelve analyses, making the total in a day 115 grains from a pan.

This may be considered small.

In the chimney of the same works he found, per 1000 cubic feet, ·086 grains arsenic. 500 cubic feet of air were used in each experiment. The coke from the tower of the same works was found to contain 2·886 per cent. of arsenic, and a great deal in some of the deposits from the pan gases.

ARSENIC AND COPPER.

Mr. Dugald Campbell some years ago found arsenic in iron pyrites in so many places—coal, I believe, included—that one was inclined to believe it a constant accompaniment. I looked for it in coal pyrites, and then found it in thirteen out of fifteen specimens; so that we must now add arsenic to the sulphuric acid of commerce, for manufacturing purposes, whether made from sulphur, or, in the more frequent method, from iron pyrites, *always contains arsenic.** It is present chiefly in the form of arsenic acid, but it is capable of leaving the acid and of forming several volatile or gaseous compounds with other very common substances. And there are several very deadly forms in which it may be present during the manufacture of Bone Manure. It would take a very extended enquiry indeed to determine the various forms in which it may be accidentally and unsuspectedly present in the vapours disengaged from bones while under the action of sulphuric acid. A volatile chloride seems the most frequent form according to my observations, and arseniuretted hydrogen gas is probably evolved but *arsenic is certainly present* in the vapours referred to. Chemical tests are not always sufficient to determine the precise combination of arsenic, but they are abundantly sufficient to determine the fact that arsenic *is present*, *and that it comes off with the vapours evolved in the manufacturing process*. In laboratory experiments conducted by professional chemists it has happened not unfrequently that life has been lost and life endangered through the unsuspected contamination of sulphuric acid with arsenic, and the inhalation of vapours proceeding from the matters acted upon by the sulphuric acid. The symptoms produced by the poison in such cases are peculiarly characteristic, and they have been carefully recorded by competent observers. And, in connection with the present enquiry, I feel it incumbent upon me to state that the symptoms so recorded are in perfect accordance with the symptoms detailed to me as having characterised the sudden illness and rapidly following death of the late Mr. John Fraser of Bunchrew.

But there is another class of gaseous exhalations proceeding from decomposing animal matter, the composition of which are unknown to the chemist, but the deleterious nature of which are known to the physician. These are 'miasms,' or 'morbid poisons,' or 'organic poisons," as they have variously been called. The nature and mode of action of a morbid poison is altogether different from that of a chemical poison. The individual who suffers from a morbid poison, *e.g.*, fever or cholera, exhibits a series of symptoms following a regular course, subject to modifications according to the severity of

number of impurities in the atmosphere of our towns. True, it has not been obtained directly from the atmosphere, but we must believe it to pass into the air with the sulphur. One or two coal brasses (as the pyrites in coal are called) contained copper, a metal that is also to some extent volatilised, as may be readily observed wherever copper soldering takes place. Although an extremely small amount of copper is carried up from furnaces, it is not well entirely to ignore it. The amount of arsenic, however, is very likely, not without considerable influence; and we may probably learn the reason why some towns seem less affected than others by the burning of coal, by examining the amount of arsenic as well as sulphur. I do not doubt that the amount could be estimated in the air of places where there are many copper works. Other metals might be mentioned.

* See Part II. for estimate of quantity.

the dose, the state of bodily habit, &c. Thus the venereal or small-pox matter causes an ulcer different in its character and progress and effects on the constitution of the individual from the ulcer caused by a drop of sulphuric acid or a hot iron. In the one case we have a local 'injury,' in the other a constitutional 'disease.' The greater number, and probably all, of the diseases caused by morbid poisons are communicable from the persons affected to another in health, in this respect differing from ordinary diseases.

It is only by a clear recognition of the distinction that exists between the character and effects of *chemical poisonous agents* of known composition, and the character and effects of *organic poisonous agents* of unknown composition that we can rightly appreciate the probable effects of exposure to the products of decomposing animal matter.

We may have both chemical poisons and morbid poisons as the products of the decomposition of animal matter. We may have at one time merely an injury, at another time we may have a disease. Some of these exhalations, both chemical and animal, are cognisable by the sense of smell, and may cause a nuisance by being a 'bad smell,' although not sensibly injurious to health. But all the morbid poisons are perfectly inodorous—have no smell whatever. It may happen, therefore, in ninety-nine cases of nuisance caused by a bad smell, that there may be no morbid poison, no cause of disease present, but in the hundredth case the morbid poison may be present, and when it is present it is in the organic matter, in the dead matter, in the decomposing matter, from which a bad smell may be proceeding. It is not, therefore the bad smells that are most to be feared—it is the possible presence of a morbid poison which is so often found to co-exist with the bad smell. Moreover, there is in these emanations from decaying matter a *plasma* or condition of things which *favours the development of* epidemic and contagious disease.

Thus it has been abundantly demonstrated that the breathing of an atmosphere tainted with the products of animal decomposition is the most potent cause of diarrhœal ailments. This hurtful influence is occasionally shown in an evident manner, but it is not constant. It depends on conditions as yet imperfectly known, such as the mode of decomposition, the nature of the emanations, their degree of concentration, the resistance more or less great which the organism can oppose to them in virtue of the individual force or of the acquired habit, and, lastly, the counteracting influence of surrounding conditions. A knowledge of their nature, and an apprehensive belief in their potency will greatly add to the hurtful influence of smells, which may be offensive smells and nothing more, while on the other hand habit may neutralise more or less completely the otherwise poisonous properties of certain emanations. Students of medicine, for example, become accustomed to the dissecting-room, and tanners and scavengers follow with seeming impunity their disgusting employments. But here there are counteracting influences. There are intermissions of employment—changes of locality during meal hours and hours of sleep—plentiful food, &c., and above all there is usually the best condition of safety, viz., the employment itself, or much of the individual's time being exercised in the open air. I am well satisfied that every occupation where it is alleged that vapours proceeding from decaying animal matter are inocuous is pursued either in the open air or in a well ventilated locality.*

Although there is much that is obscure in the mode of action, there is much that is actually known of the hurtful influences of decaying animal matter, and I may profitably refer to some illustrative examples. The conclusions summarised in Parliamentary Reports on interments on towns, in reports of the Board of Health, &c., show conclusively that the vapours given off from crowded churchyards, vapours in every essential respect analogous, if not identical with those proceeding from heaps of decaying bones stored in a Bone Manure factory, if not productive of any specific disease, yet increase the amount of sickness and mortality in the neighbourhood. The experience of many campaigns shows that where soldiers are exposed to the advanced putrefaction of animal remains there is a decided unfavourable influence upon health. At Sebastopol a great number of bodies of horses lay putrefying in the French camp, and the medical authorities describe the effect as most disastrous, and conjecture, moreover, that the spread of the typhus was connected with this condition. But an example in every way appropriate to the present enquiry is found in the experience of Christchurch Workhouse at Spitalfields.† In 1847 many of the inmates were seized with violent attacks of diarrhœa. A manure factory had been established close by the workhouse, and it was observed that these attacks of disease occurred whenever the works were actively carried on, and particularly when the wind blew from that quarter. The cases of illness in the workhouse infirmary also acquired a malignant and intractable character. In December of the following year cholera occurred in the neighbourhood, and suddenly thereafter, in a single morning, sixty of the children were attacked with violent diarrhœa. In consequence of this outbreak the owner of the manufactory was obliged to stop work, and the children rapidly recovered. Five months afterwards the works were resumed. In a day or two subsequently, the wind blowing from the manufactory, a most powerful stench pervaded the building. In the night following forty-five of the boys, whose dormitories directly faced the manufactory, were again suddenly seized with severe diarrhœa; whilst the girls, whose dormitories were in a more distant part and faced in another direction, escaped. The manufactory having been again

* For general references to the effects of Animal Miasms, see Tardieu's Dict. D'Hygiène, vol. i., p. 517; vol. iii., p. 433; Chadwick on Interment in Towns; Board of Health Reports on Extra Mural Sepulchre; Vernois' Hygiène Industrielle, vol. ii. p. 60; Levy Traité D'Hygiène, vol. ii. p. 453; Parke's Hygiene, 1869, p. 113; Wilson's Handbook of Hygiene, 1873, p. 67, &c., &c.

† Carpenter's Human Physiology, 6th Edit., p. 313.

suppressed, there was no subsequent return of diarrhœa. This example fairly illustrates the potency of an atmosphere charged with decaying animal emanations in rendering the system liable to the attacks of epidemic and contagious diseases of various kinds, and an example of what may be expected where an epidemic influence invades a locality.

It must therefore be accepted as a thoroughly demonstrated fact, that vapours proceeding from decaying animal matter in the air exercise a pernicious influence on the human body, depressing or impairing all the functions, and particularly the functions of those organs with which it is brought into contact; manifesting itself constitutionally by febrile conditions accompanied with prostration, and locally by affections of the respiratory and alimentary canal. Therefore, during a period of epidemic disease, if entrusted with large powers—as has happened on several important occasions—I would energetically protest against the operations of such a bone manure work as that under consideration being permitted to go on for a single day. And if the works were not closed, I would warn the people of the neighbourhood to remove from the vicinity.

Throughout Europe at the present time, the doctrines of scientific surgery and its practice are being powerfully directed, through the teaching of its most distinguished exponents, to *an antiseptic method* of treating open wounds of every kind. Numerous chemical and mechanical appliances are being contrived and applied with the exclusive object of preventing the access of germs of disease found to exist in the emanations of decaying animal matter. I need scarcely point out the unfortunate position of the medical man who has to treat an open wound—say a compound fracture—in a locality the air of which abounds in decomposing animal matter. Still more, however, is to be commiserated the condition of his unlucky patient.

So much for exhalations of unknown composition, and of uncertain or variable character, which proceed from Bone Manure. With regard to the matter of fact, of arsenic being associated with the vapours of Bone Manure, I have to state that—

I have made a special investigation into the character of the vapours given off during the manufacture of Bone Manure, with special reference to the presence of arsenic in said vapours, and

(1.) Have ascertained, by references to medical literature and to the literature of technical chemistry, that the sulphuric acid of commerce is always contaminated with arsenic; and

(2.) Demonstrated by experiments in laboratory that when crushed bones are treated with commercial sulphuric acid in the manner of manufacturing Bone Manure, there are given off vapours largely impregnated with arsenic; and

(3.) Obtained samples of the vapours condensed on the walls of the mixing-room of the Manure Factory at Bunchrew, and on subjecting the material to careful experiment, found it largely impregnated with arsenic; and

(4.) Obtained a sample of the vapours at another Manure Factory, which were condensed and collected several hundred feet distant from the place where they were disengaged, and found in the deposit the presence of arsenic; and

(5.) Obtained samples of the sulphuric acid and of the crushed bones which were being used at the Bunchrew Manure Works, and ascertained that the sulphuric acid was impure and largely contaminated with arsenic; and

(6.) In association with Dr. Machattie, Consulting Chemist, and within his laboratory, have repeated certain experiments with ordinary sulphuric acid and crushed bones, and detected in the vapours the presence of arsenic. At same time and under the same conditions I have treated the crushed bones obtained at Bunchrew works with the sulphuric acid obtained from the same works, with the result of demonstrating the presence of arsenic in the vapours given off; and

(7.) I have obtained the friendly aid of several professional chemists of high attainments and position, and the results of their concurrent experiments have corroborated, in every particular, those obtained by myself.

J. A.

PART II.

ON THE PRESENCE OF ARSENIC IN THE VAPOURS OF BONE MANURE.

In my report to Counsel of my investigation as to the conditions of the Bunchrew Manure Work, I state that *I have demonstrated, through careful, frequent, and altogether exhaustive experiments, the presence of Arsenic in the vapours which are disengaged during the manufacture of Bone Manure, and I explain that this Arsenic is derived from the sulphuric acid—made from iron pyrites—used for manufacturing purposes, which always contains Arsenic.*

This statement was communicated on the eve of trial to Dr. Stevenson Macadam of Edinburgh, a fellow-witness with me in the case. Unfortunately the time was too limited for him to investigate the facts which I had brought forward for the first time, and as these were entirely new, and rather startling to him as well as to the other professional gentlemen engaged in the case, he very properly did not commit himself to their acceptance till he had ample opportunity of personally investigating the subject.

At a consultation with Counsel, held in their Chambers, at which were present the prosecutor in the case (Mr. Fraser), the legal gentlemen, and all the medical witnesses, Dr. Macadam stated fully and distinctly his views on the "arsenic theory," so far as he understood it. He mentioned that any arsenical impurity which might formerly have existed in commercial sulphuric acid did not now exist, because that it was now made from *copper* pyrites instead of, as formerly, from *iron* pyrites. Any arsenic present in sulphuric acid could only, therefore, be in such infinitesimal quantity as to be *altogether insignificant.* But setting aside completely the sources from which sulphuric acid was made, and even assuming that arsenic should happen to be present in the acid, *none of that arsenic could theoretically, or would practically, pass into the vapours disengaged during manufacture, but would, and did, remain in the manure.*

It was suggested by both Mr. Asher and Mr. Trayner, the Counsel in the case, that he might test off-hand the quality of the sulphuric acid made from iron pyrites, but he stated that that was a matter of some difficulty, as it was so rare, that he did not actually know where he could lay his hands upon a sample in Edinburgh.

An interesting discussion, adjourned from the Chambers of Counsel to the Witnesses' Hotel, terminated at a very late hour by Dr. Macadam undertaking, at my suggestion, to dissolve a given percentage of arsenic in pure sulphuric acid, and treat bones with the same after the usual manner of making Bone Manure. He also took with him two samples of "condensed gases" which had been disengaged in two Manure Works, and which I stated contained arsenic, and these samples he also undertook to examine.

On the following morning, while the trial was in progress, Dr. Macadam informed the Counsel, agents, and witnesses that he had made that morning the promised experiments, and with entirely negative results. This he had expected, and his night's careful reflections had only added strength to his previous convictions. In fine, he so impressed Counsel that they reluctantly resolved "to drop the arsenic theory," to avoid the risk of collision between the *Medical* witnesses on the one hand and the *Chemical* witness on the other.

This decision of Counsel, although prudent in the interests of their client, was a great mortification to myself, and a disappointment to the other Medical witnesses, some of whom, viz.:—Dr. Littlejohn, Dr. Mackay of Inverness, and Dr. Dunlop of Glasgow, did not fail to express their surprise at the result of the experiments made by Dr. Macadam and his reasoning therefrom, more especially as it seemed to them that the symptoms which Mr. Fraser had during his fatal illness very closely resembled those with which they were familiar as indications of poisoning by arsenic, and regarding which they were prepared to speak in the witness-box. And it was also a source of regret to them that the opinion I had formed of the probable cause of Mr. Fraser's death, and the fact that I had demonstrated the presence of arsenic in the Bone Manure vapours, were not corroborated by Dr. Macadam.

Counsel, however, elicited during my examination the statement that vapours disengaged in the "mixing-pit" of the works under review had been observed by me to be condensed on the ceilings and walls of the apartment, and to have formed there an encrustation—that I had carried away a sample of the same and found it to contain arsenic—and that I accounted for the arsenic by alleging its invariable presence in Bone Manure Manufacturers' sulphuric acid. It may be mentioned here that Dr. Machattie of Glasgow, who had been summoned by telegram, was fully prepared to corroborate that point in my evidence which related to arsenical vapours from Bone Manure. But Counsel evidently thought it sufficient that the suggestion of a novel and dangerous aggravation of the general characters of a nuisance should be imported into the case, and I have no doubt that this was the most prudent policy under the circumstances.

Now that the legal exigencies of the case have passed, there remains for settlement the scientific question which has been raised between my friend Dr. Macadam and myself.* It is interesting to the circle where it originated, and it is of public importance. When I stated that "the facts were so simple and so obvious when explained, that it seems quite marvellous that suspicion and enquiry has not previously been directed to the subject," I did not anticipate the possibility of the facts being denied, and last of all by a Chemist. I did not therefore enter into details. I must now show that my enquiry was painstaking—that my facts were easily demonstrable, and had been demonstrated. And it is with extreme gratification that I avail myself of the privilege of publishing, in their own words, the corroborations of eminent professional Chemists, whose position as scientific men is unassailable, and in whose association I am able to disregard, if not forget, that my facts had ever been called in question. If somewhat tedious in detail, it is because I cannot otherwise do justice to the gentlemen who have so conclusively verified my observations and established all that I have advanced.

In a careful study of numerous works on general and on Technical Chemistry, conjoined with practical observations, there have been impressed on my mind the following propositions:—

First, that the chief sources from which manufacturers' sulphuric acid is obtained are very largely contaminated with arsenic.

Second, that sulphuric acid, before being subjected to special purifying processes, is always charged with arsenic and other impurities or substances of a foreign nature.

Third, that the processes by which such impurities can be removed are of a very costly character.

Fourth, that for the large majority of manufacturing operations in which sulphuric acid is employed, there is not required a pure acid.

Fifth, that in the conduct of chemical operations there have occurred cases of loss of life to individuals, otherwise well informed, owing to the accidental and unsuspected presence of arsenic in the materials employed.

And, as the result of a special investigation, I now add a *Sixth* proposition, viz., that in the manufacture of Bone Manure there are given off vapours impregnated with arsenic, derived from the sulphuric acid employed in the process. I will deal with these propositions *seriatim*.

(1.) *The sources from which commercial sulphuric acid is obtained are very largely contaminated with arsenic.*

The accidental or unsuspected presence of arsenic in sulphuric acid was noticed for the first time in Britain by Dr. G. O. Rees,†

* To ensure perfect accuracy in stating the question, I have submitted printed proofs to the gentlemen who took part in the discussion.

† London Medical Gazette, February 5, 1841.

Lecturer on Medical Jurisprudence, London, who states that he found 22½ grains of white arsenic in 20 fluid ounces of supposed pure acid, sold to him at 8d. per pint, and that on procuring another sample direct from Apothecaries' Hall, he found a still larger quantity. A few days afterwards Mr. H. Watson,* Consulting Chemist at Bolton-le-Moor, announced that for several months he had been aware of this contamination, and had examined numerous specimens. The smallest quantity of arsenic he had found was 35½ grains in the fluid pint, and the latest sample had yielded 5½ grains in 1000 grains by weight of acid. After this date, all standard works on Toxicology, irrespective of special memoirs on the subject,† have references to this impurity as a source of fallacy in the application of tests, as well as a cause of danger in the conduct of laboratory operations.

Turning to works of scientific and technical chemistry,‡ there is a superabundance of references to the fact of the contamination of commercial sulphuric acid with arsenic as a necessary consequence of the sources from which the acid is derived. For a very long period the greater portion of sulphuric acid used for all purposes was prepared from native sulphur obtained from Sicily; but owing to the unwise action of the government of that country in 1838, the price of sulphur was raised from £5 to £14 per ton. Manufacturers were consequently forced to seek some other source of supply. This was found in pyrites, or as it is usually called, iron pyrites. Its composition is a bi-sulphide of iron, containing about 47 per cent. of iron and 53 per cent. of sulphur; but it almost invariably contains trifling admixtures of other metals, as gold, copper, arsenic, antimony, &c. It is found in considerable quantities in Great Britain and Ireland, and seems indeed to be universally diffused. Iron pyrites, whether of home produce or from abroad, occasionally contains copper in quantity sufficient to make the extraction of the metal remunerative —*a good average being* 3 *to* 3½ *per cent.*,—and when there is the workable amount of copper it is occasionally termed *cupreous* iron pyrites. This cupreous or coppery iron pyrites is scientifically and technically altogether different from "copper pyrites," the yellow copper ore of Cornwall. Copper pyrites is *a double sulphide* of copper and iron, containing about 35 *per cent. of copper*, or ten times as much as the

* London Medical Gazette, February 19, 1841.

† Bloxam in Chem. Soc., Qu. Jour., xv. 32. Bussy and Buignet in Journ. de Pharm. et de Chemie, Sept. 1863, p. 77, and vol. 45, p. 465. Blondlot in Compt. Rendu, vol. 58, p. 769, &c., &c.

‡ Fowne's Chemistry, 1873, pp. 203 and 454. Gmelin's Hand-book of Chemistry, 1849, vol. ii., p. 183. Ure's Dict. of Arts and Sciences, 6th edit., vol. iii., p. 862, *et seq.*, also 7th edit., vol. iii., p. 963. Muspratt's Chemistry of Arts and Manufactures, &c., vol. ii., p. 1023, *et seq.* Watt's Dict. of Chemistry, vol. v., p. 573. Knapp's Technology, 1848, vol. i., pp. 226, 252, &c. Richardson & Watt's Chemistry applied to Arts and Manufactures, 2nd edit., 1863, vol. i., pp. 68 and 112. Wagner's Chemical Technology, 1872, p. 206, &c. Pereira's Materia Medica, vol. i., p. 368, &c. Christison's Dispensatory, 1842, p. 48. Phillip's Metallurgy, 1874, p. 126, &c., &c.

iron pyrites, with which, through ignorance of the distinction, it may be confounded.

About the year 1853, pyrites containing a small per centage of copper began to be imported from Spain and Portugal, and a considerable quantity of ordinary pyrites was derived from Norway and other countries. Pyrites of home produce also continued largely in use; but about ten years ago the Tharsis Sulphur and Copper Company obtained the use of a patent process for the more profitable extraction of the copper which may exist in iron pyrites, and at same time obtained possession of an extensive tract of open mines of iron pyrites in Spain, containing the workable amount of copper I have referred to, and since that date the use of home pyrites is steadily decreasing, while the imports from abroad are as steadily advancing. The total produce of the United Kingdom for 1872 was 66,000 tons, of which 5000 tons belonged to Cornwall and 43,000 tons to Ireland. This was a considerable falling off from the preceding year, and in 1873 there was a still farther falling off of about 7000 tons. In 1872 the imports from abroad amounted to 516,299 tons,* chiefly from Spain and Portugal, about one-half being brought over by the Tharsis Company. During the *eleven months* ending November 30, 1875, there were imported 503,961 tons, being an increase of 13 per cent. against the corresponding period of 1874. The steady increase in the quantity of pyrites imported is, however, best shown in the following figures, taken from J. Berger Spence's Commercial Report for June 3, 1876:—

	1874.	1875.	1876.
4 months ending April 30,	184,891 tons.	190,581 tons.	204,443 tons.

But it is the sulphur that constitutes the chief value of iron pyrites, and it is in consequence often referred to in technical works under the name of sulphur ore. About two-thirds of the pyrites brought from Spain and Portugal is sold first to the sulphuric acid manufacturer, who extracts the sulphur by roasting, and the "cinders" or residual burnt ore is returned or re-sold to the copper works, where the metal is extracted to the amount of 12,000 tons annually.

It is from iron pyrites—or, to use the familiar commercial term, "pyrites"—that nearly all the sulphuric acid employed in large manufacturing works is now produced, viz., alkali works, manure works, &c. Finer qualities of acid made from Sicilian sulphur are employed for finer purposes in the trades and arts—as in bleaching, dyeing, calico-printing, gilding, &c. It can be, and is, made also from the spent sulphur in "vat waste," &c., and there are other sources from which it may be occasionally manufactured. Thus, it *may be*, and in some places *has been*, made from "*copper* pyrites," but such exceptional manufacture can at any time form only a very insignificant portion of that which is consumed in this manufacture. It is therefore an altogether inaccurate and misleading form of

* Simmond's Waste Products, 1873, p. 409.

expression in the mouth of a chemist when it is stated that sulphuric acid is now-a-day made from *copper* pyrites. And there are no grounds whatever for saying that purer sources now exist than formerly did for the manufacture of sulphuric acid. All facts, indeed, go exactly in the contrary way.

But that which most concerns the present enquiry is the great fact that "pyrites," whether called *iron* pyrites, or *coppery* pyrites, or *sulphur ore*, in short, all the pyretic compounds used in the manufacture of sulphuric acid, contain arsenic, and contain it in large quantity. This is made evident in the following table which I have constructed from numerous analyses of what may be considered fairly representative specimens. To make the matter more clear I have calculated, from the percentages given in the analyses, the quantity of arsenic contained in each ton of pyrites, and also the number of tons of pyrites belonging to each sample which would contain 1 ton of arsenic.

No.	Quality of Pyrites.	Arsenic per cent.	Arsenic *in each Ton* of Pyrites. *Lbs.*	*Oz.*	*Grs.*	No. of Tons of Pyrites which contain *One* Ton of Arsenic.
1	Spanish,[1]	0·33	7	6	119	303
2	,, [1]	0·41	9	2	413	244
3	,, [1]	1·10	24	10	105	91
4	,, Seville,[2]	0·62	13	14	91	161
5	,, ,, [3]	0·52	11	10	161	192
6	,, Tharsis,[4]	0·40	8	15	151	250
7	,, Rio Tinto[5]	0·56	12	8	308	179
8	Portuguese,[6]	0·47	10	8	196	213
9	Belgian,[1]	0·20	4	7	297	500
10	,, [1]	0·31	6	15	45	323
11	,, [1]	0·41	9	2	413	244
12	Irish,[1]	0·18	4	0	224	555
13	,, [1]	0·40	8	15	151	250
14	,, [1]	0·60	13	7	175	166
15	,, [7]	2·11	47	4	98	47
16	Cornwall,[1]	0·40	8	15	151	250
17	,, [1]	0·50	11	3	87	200
18	,, [1]	0·90	20	2	325	111
19	,, [1]	1·16	25	15	86	86

[1] R. C. Clapham in Richardson & Watt's Chemistry of Arts and Manufactures, 2nd edit., vol. i., par. iii., pp. 13 and 15.

[2] Seville S. & C. Co.'s *Average* of three analyses, by Dr. Milne.

[3] Do. do. Analysis of an *average* sample, by Mr. "M." I am informed by the Secretary that this Company imports from 20,000 to 25,000 tons annually.

[4] Tharsis Sulphur and Copper Co.'s Official *Average*.

[5] Rio Tinto Co., Analysis by Mr. "I."

[6] Claudet's *Average* Analysis of Mason's San Domingo Mines in Ure's Dict. of Arts, &c., 7th edit., vol. iii., p. 676.

[7] R. D. Thomson in Muspratt's Chemistry of Arts and Manufactures, vol. ii., p. 1023.

The arsenic shewn in this table is calculated as a metal, because the percentages give the amount of metal of arsenic which can be extracted from the pyrites. But when pyrites is roasted in the manufacture of sulphuric acid, this metallic arsenic becomes oxidised, and is converted into arsenious acid, or subsequently into arsenic acid, the two most familiar forms in which the poison is known and dealt with. In these forms the actual quantity of the poison is increased—in round numbers—by an addition of one-third to one-half. One pound of metallic arsenic when it is oxidised forms 1 lb. 5 oz. 52½ grs. of *arsenious* acid or "white arsenic" as it is called in commerce, and in a higher oxidation it forms 1 lb. 8 oz. 233 grs. of *arsenic* acid. It is in the latter form that arsenic is usually present in sulphuric acid, and this important correction upon the foregoing table must be kept in view when estimating the amount of arsenical contamination in vitriol derived from pyrites.

In every instance the pyrites referred to were imported and produced for the manufacture of sulphuric acid. I might extend the list, but to no useful purpose. The arsenic may range from the extreme amounts shewn in the table, down to *nil* in exceptional instances. There are specimens of impure pyrites known in the coal districts as "coal brasses," of which I have seen various published and unpublished analyses, and which contain little arsenic. In Richardson & Watt's Chemistry there are given analyses by Browell and Marico, of iron pyrites from Belgium, Piedmont, Pomerania, and Sweden, which contained no arsenic, or only traces. But pyrites which contain little or no arsenic seem to contain little or no copper, and are consequently little used because comparatively unprofitable, while the importations of *cupreous* iron pyrites (which always do contain arsenic) are yearly increasing. It would therefore be an incorrect average of commercial pyrites, if the extremes of arsenic found in all pyrites are included. But a good mean will be obtained from the analyses of the Rio Tinto, the Tharsis, and the San Domingo pyrites, the two last being averages, recently made, and the imports of the three companies representing about 600,000 tons, or fully five-sixths of the entire quantity of pyrites, used in this country, of which we have any reliable information.* The mean of these three pyrites gives a good, and, as I am well assured, a thoroughly reliable average of 0·477 per cent. of arsenic, from which it is clear that a ton of arsenic is contained on an average in every 210 tons of pyrites, a rather curious commentary on the alleged purity of the pyrites from which sulphuric acid is made now-a-days. Only a slight knowledge of the process of vitriol making is required to make it understood why *the greater part of this arsenic is liable to be, and actually is, retained in the vitriol chamber or in the flues of the factory.*

* In 1874, according to the Annual Report of Tharsis Co., the pyrites invoiced to the customers was 240,863 tons. In Phillip's Metallurgy, edition 1874, p. 376, the exports to this country of San Domingo pyrites are stated to be about 175,000 tons annually; and I am officially informed that the imports of Rio Tinto pyrites amount to 200,000 tons annually.

(2.) *Sulphuric acid, before being subjected to purifying processes, is always charged with arsenic, &c.*

In the manufacture of sulphuric acid, the pyrites is burned in kilns supplied with a limited amount of air; the products of combustion being thence conducted into leaden chambers.

Sulphuric acid cannot be manufactured directly from pyrites in a state of purity, because in roasting the pyrites the temperature necessary to expel the sulphur in the form of sulphurous acid also volatilises arsenic, zinc, antimony, &c., &c., contained in the pyrites, the fumes of which are carried forward into the chambers and contaminate the acid. As to the extent of this contamination there is no fixed data. Much depends on the care taken by the acid manufacturer. But an estimate may be formed of what is possible, and of what is probable.

From the average I have already given I find that 100,000 tons of pyrites contain 477 tons of arsenic. When these are roasted by a careful manufacturer, all the sulphur amounting to 48 per cent., excepting 2 or 3 per cent., is expelled, and when the residual burnt ore is examined it is found that along with the sulphur there has been driven off 72·7 per cent. of the arsenic. This statement is furnished to me as the result of operations on a very large scale. Therefore, rather more than 346 tons of arsenic have been volatilised and passed along with the sulphur towards the vitriol chamber. A less carefully conducted process leaves a larger amount of arsenic in the residual burnt ore, but it also leaves a larger amount of sulphur, so that the relative amounts remain much the same. The same pyrites produce 140,000 tons of sulphuric acid of 148° Twaddell, and this is considered a good result. From these figures it is easy to calculate that rather more than one ton of metallic arsenic for every 404 tons of acid has gone into the vitriol, or into the flues of the factory. This gives rather *more than 5½ lbs. of metallic arsenic for every ton of sulphuric acid*, but it does not follow that this quantity is contained in every ton of acid, for it is sometimes much greater and sometimes much less.

Several causes contribute to the difficulty of obtaining a thoroughly reliable average. In the first place, the enquiry is altogether new, and little help is derived from recorded observation in which the statements are decided enough as regards the actual contamination with arsenic, but very vague as regards exact quantities. Then, at one time the acid is prepared from pyrites which contains less arsenic than may be present in the next supply. The weak acid loses by evaporation nearly a third of the water it originally contained, and this concentration increases the relative proportion of arsenic. Therefore concentrated acid of the usual standard of 1·845 sp. gr. cannot be properly compared with the watery "chamber acid" which ranges from 1·2 to 1·6 sp. gr. From the same pyrites and during the same making the chamber acid varies in the amount of contamination. For it is customary to use in the manufacture of sulphuric acid, a succession of chambers—usually three,—and I have found by direct experiment that the first chamber is liable to receive a larger amount of impurity than the others. These successive chambers carry out practically the suggestion of Dr. Ure, of a series of "gaseous subsidence lakes,"* and No. 1 chamber may contain nearly 11 lbs. of arsenic in a ton of vitriol, while No. 3 chamber may contain only 1½ lbs. Still farther to complicate the difficulty there is the fact that arsenic is present in vitriol in two conditions, viz., as *arsenious acid* and as *arsenic acid*, the first of which is in comparison sparingly soluble in cold sulphuric acid, while the latter is soluble to a large amount. And as there are various altering conditions during the manufacture which tend at one moment to develope the very soluble *arsenic* acid, and at another the sparingly soluble and frequently-precipitated *arsenious* acid, it happens that one sample of acid contains a minimum quantity chiefly as arsenious acid, and another a maximum of arsenious and of arsenic acid combined.

Nevertheless, it is obvious, or at least very probable, that the arsenic in sulphuric acid is in a ratio with that which is contained in the pyrites. In an endeavour to determine this point, I encountered some rather curious experiences. A manure manufacturer, who makes his own vitriol, uses an impure kind of pyrites of native produce, which, according to an analysis he obtained, contains only "traces" of arsenic. I got his vitriol examined, and arsenic was found in considerable quantity. The analysis of pyrites was accurate only on the point that interested the manufacturer, viz., the proportion of sulphur, and it was probably to this point that the attention of the analyst had been specially directed. But it was professedly a quantitative analysis, and it was misleading. In another case an acid manufacturer had his acid tested for his own satisfaction by a very careful chemist, and it was found to contain more than 10 lbs. of arsenic to the ton of acid. But he did not know whether this was a large or a small amount, and, as I shall presently explain, he had no source of information to which he could refer. Some months afterwards I had his acid tested for the present enquiry, and with a corresponding result. Now, the curious point in this second case is the fact that the pyrites merchant had a formal printed circular in use, showing *inter alia* only a tenth or fifteenth part of the arsenic contained in any other pyrites in the market, while in actual fact there was extracted from the acid about ten times as much arsenic as could have got there according to his advertised analysis. I got samples of his pyrites analysed for my own satisfaction, and arsenic was found in quantity exceeding the average. It is right to add that the pyrites merchant, as soon as his attention was directed to the anomaly, stated that he would withdraw the circular, and I otherwise satisfied myself that there was no intentional misrepresentation. The original sample analysed for the pyrites merchant had evidently not represented the bulk, although the important items

* Ure's Dict. of Arts and Sciences, 6th edit., vol. iii.

desirable in a *commercial* analysis, viz., sulphur and copper, were accurately given. But it should be obvious that, however accurate the analysis may be of a single sample of an importation, it is quite absurd to suppose that such analysis can apply to, or guarantee, the varied composition or the general quality of *the successive importations of after years.* Any such application of an analysis is a misuse of a chemist's name and reputation. And, while referring to fair dealing with chemists, I farther suggest—and I apply the spirit of the suggestion to commercial men generally—that a *full analysis* showing the exact quantities of the very various constituents of pyrites cannot possibly be obtained for the small fees to which the analyst is frequently restricted, and therefore such pretentious and misleading certificates should rarely be asked for or published.

Of the many able observers who, during the last 35 years, have devoted laborious investigations to prove that sulphuric acid always contains arsenic, and to devise measures for freeing it from that contamination, I can find only four who condescend upon actual quantities, viz., Dr. Rees, Dr. O'Reilly, Mr. H. Watson already referred to, and a German chemist named Thorn, who has recently made some observations on this point. Other writers, as Bloxam, Bussy and Buignet, and Blondlot, limit their remarks to the fact of the presence of arsenic, using only such indefinite expressions as "arsenic found in quantity," "very distinct evidences of arsenic," &c. The same vague state of information prevails among professional chemists, for, with one exception, viz., Mr. Tatlock, who made a quantitative examination for a local manufacturer of acid, who obligingly showed me the analysis, all with whom I have discussed this point could neither give nor refer to any source of information or precise statement of quantity. In looking over laboratory memoranda of the late Dr. Penny, there is similar proof that in his great commercial experience he had not made a quantitative analysis of the arsenic in sulphuric acid. I have therefore endeavoured to give greater precision to the state of our knowledge by procuring, from various manufacturers, samples of sulphuric acid, and getting them *quantitatively* examined for arsenic. Dr. Mills, of the Young Technical Chemistry Chair, naturally took considerable interest in determining this practical point, and I am especially indebted to him for six careful analyses of sulphuric acid. My friend Mr. "M." made a still larger number, including numerous *quantitative* analyses, and he has in addition furnished me with a most valuable *average* analysis of sulphuric acid made from Tharsis pyrites. From 108 vitriol chambers there were taken daily samples of acid, making in all 432 samples. All these samples were mixed together, and a *quantitative* analysis made. It is with great satisfaction that in my struggle to obtain *a good average* I have been so successful. The following table is therefore presented as unique, fairly comprehensive, and thoroughly reliable.

No.	Sulphuric Acid made from.	Specific Gravity.	Percentage of Arsenious Acid.	Arsenious Acid extracted from *One Ton* of Sulphuric Acid. Lbs.	Oz.	Grs.	Analyst.	Remarks.
1	Sulphur,	1·82	Traces.				Mr. "M."	Purest manufactured—cost £56 per ton.
2	Do.	1·80	0·010	0	3	256	Dr. Mills.	Cost £7 10s. per ton.
3	Pyrites,	1·84	0·1433	3	3	157	Dr. G. O. Rees.	Another sample contained larger amount.
4	Do.	1·84	0·220	4	14	371	H. Watson.	Smallest quantity in numerous samples.
5	Do.	1·84	0·550	12	5	53	Do.	Largest do. do.
6	Do.	1·84	0·600	13	7	175	Dr. O'Reilly.	6 additional samples all largely contaminated.
7	Do. Irish,	1·68	0·034	0	12	81	Dr. Mills.	An exceptional specimen.
8	Do. Spanish,	1·44	0·050	1	1	403	Do.	
9	Do. do.	1·51	0·070	1	9	39	Do.	From No. 3 vitriol chamber.
10	Do. do.	1·54	0·490	10	15	270	Do.	From No. 1 do.
11	Do. do.	1·74	0·120	2	11	4	Do.	
12	Do. do.	1·70	0·505	11	4	434	Mr. Tatlock.	Cost about £4 per ton.
13	Do. do.	1·58	0·330	7	6	119	Dr. Machattie.	
14	Do. do.	1·58	0·140	3	2	77	Dr. Milne.	
15	Do. do.	1·61	0·440	9	13	305	Do.	From a No. 1 vitriol chamber.
16	Do. do.	1·48	0·0624	1	6	159	Mr. "M."	
17	Do. do.	1·50	0·0476	1	1	26	Do.	
18	Do. do.	1·55	0·430	9	10	49	Do.	
19	Do. do.	1·73	0·1617	3	9	417	Do.	
20	**Do. do.**	**1·50**	**0·0816**	**1**	**14**	**370**	Do.	**An average of 432 samples made from Tharsis Pyrites.**

Of the 20 analyses of acids represented in the preceding table, 15 were made for the purposes of the present enquiry. I had a larger number made which are not included, partly for want of room, partly because they merely repeat each other. They range from the guaranteed pure article, costing at the rate of £56 per ton, and used in the scientific analyst's laboratory—the fine sulphur acid costing £7 10s. per ton, used in the finer arts generally—the good quality of pyrites acid costing about £4 per ton, and having the most extended applications of use in manufactures, down to the crudest chamber pyrites acid, costing, to produce, about 30s. per ton, and used largely by alkali and manure works. Excluding the absolutely pure and the comparatively pure sulphur acids, it will be seen that the smallest quantity of arsenious acid extracted from a pyrites acid was 12 oz. 181 grains avoirdupois. This acid was from Irish pyrites, and the only specimen of the kind I could obtain. It was also the last the manufacturer intended to make. I had a sample from a Scotch pyrites—a kind of "blaize," or sulphury coal shale—which contained arsenic in nearly a like proportion with the Irish, but being exceptional, I have not included it in my table. The amount of arsenious acid which can be extracted from pyrites sulphuric acid seems to range from 1 lb. to 13½ lbs. per ton in round figures. Excluding No. 20, the average derived from my table is nearly 5 lbs. 14 oz. to the ton; but this is, I think, too large for a general average, and I incline to think that 2 lbs. to 3 lbs. per ton is a fair estimate. The splendid average given in Mr. "M.'s" analysis applies exclusively to the acid manufactured from Tharsis pyrites, containing the comparatively moderate proportion of 40°/₀ of arsenic. This pyrites, however, represents nearly one-half of the entire pyrites used in Great Britain, and the acid made from it represents the best result as regards arsenical contamination that a first-class establishment can produce. These experiences show that the proportion of arsenic in vitriol corresponds with the proportion of arsenic in the pyrites from which it is made. So much for the erroneous assertion that commercial sulphuric acid now-a-days is comparatively pure, or is contaminated only to an "altogether infinitesmal extent."

(3.) *The processes by which impurities can be removed from sulphuric acid are of a very costly character.*

It is easy to understand why pure sulphuric acid should be both rare and dear. Besides arsenic, it contains lead, zinc, iron, antimony, sulphurous acid, hydrochloric acid, nitric oxide, nitrous acid, nitric acid, &c. ; not all at the same time, but any one or more may be present, and frequently are present, and all require special and complicated processes for their removal. When for any particular use it is necessary either to concentrate or to purify sulphuric acid, there is required greater skill, a higher paid class of workmen, and larger premises, besides other costly manufacturing facilities. In the mere concentration of "chamber acid" to the normal strength of 1·845 sp. gr., there requires to be separated by evaporation about 40 lbs. of water for every hundred-weight of acid. If the concentration is effected in leaden trays, then the tear and wear of apparatus is great, and the leaden impurity is increased. If in glass carboys, there are breakages and losses of acid. If in platinum retorts, then these vessels cost from several hundred to £3000 each, and consequently do not figure in the "plant" inventory of manure manufacturers who make their own acid. Nevertheless, sulphuric acid for some purposes is purified up to required standards of purity. Works on Technical Chemistry contain numerous methods for removing individual impurities as well as general, and in particular, for removing altogether or at least diminishing that "very serious drawback" which Dr. Ure describes as existing "in the presence of Arsenic in all the acid made from Pyrites." But the adoption of any purifying process raises the price of the material in a fast increasing ratio with the standard of purity desired. Thus "chamber acid" can be produced at a cost of, say, 30s. per ton, equal to about 6 lbs. for a penny. A concentrated acid of purer quality is sold at from 1d. to 2d. per lb., or from £4 to £8 per ton; while the analytic chemist and respectable druggist who must have the article as nearly pure as possible, pays 6d. per lb. wholesale, or about £56 per ton. Even at this enormous price there is no certainty of getting the article free from arsenic. From experiments by Professor Bloxam* it appears that all the sulphuric acid of commerce, even that made from the purest Sicilian sulphur, and reputed to be quite free from arsenic, gives indications of that metal when examined by delicate tests. Every sample he obtained give rings of metallic arsenic in the reduction tube. Moreover, it was found that the arsenic could not be completely eliminated either by fractional distillation, as proposed by some chemists, or even by distilling it with common salt; the residual acid still exhibiting traces of arsenic in every instance. As the entire *purification* of the commercial acid appeared hopeless, Professor Bloxam endeavoured to prepare the acid in a state of purity in the first instance, and succeeded in doing so, but admits that the process could not be economically carried out on a manufacturing scale. In corroboration, so far of Professor Bloxam, I may mention that within the last few weeks I saw a quantity of the best and the highest priced sulphuric acid, which was guaranteed to be absolutely pure, but which was so contaminated with arsenic that my friend, Mr. "M." found it necessary to re-purify and distil for use as much as was necessary for certain experiments he performed in connection with the present enquiry. This he did by diluting the acid, throwing down the acid by sulphuretted hydrogen, then re-concentrating and distilling—a tedious and costly process.

* Journal of Chemical Society, xv., 52.

(4.) *For manufacturing operations a pure sulphuric acid is not required.*

On account of the greatly increased cost with no countervailing advantages, no attempt is made either to concentrate or to purify the acid used for many manufacturing operations. The non-concentrated and non-purified acid just as it is run off from the leaden chambers, is the acid used by the manure manufacturer. "If it were necessary to concentrate or to purify," said a manufacturer to me, "I would soon cease to make manure." On this point Dr. Muspratt says* "pyrites has come into very general use amongst one class of sulphuric acid manufacturers. The great objection to the use of pyrites lies in its containing a considerable amount of arsenic. This renders the vitriol objectionable for certain purposes, but this impurity does not prevent its being used by the alkali manufacturers. In his case the arsenic does not interfere in the least; it passes off as chloride of arsenic with the hydrochloric acid gas, and condenses into a liquid state with this latter body. * * * * Arsenic is a common impurity derived from the iron pyrites from which much acid is made. For the great majority of purposes, these impurities are not found inconvenient in the arts; while on the other hand for some special uses, a process of purification must be had recourse to."

It is assuredly not for the purposes of a manure manufacturer that purification is ever resorted to. When he buys acid, he contracts for the lowest priced article that is made, of so many degrees "Twaddell," and makes no reference to arsenic or to any of the other contaminations invariably present in the crude acid. But in point of fact, a manure manufacturer who does not make his own acid is an exception in the trade, where it is a maxim that the real profit of the manufacturer only begins when he makes his own acid. A manure manufacturer sees as little necessity or inducement to incur cost or delay in purifying processes as he does to perfume his commodity with Eau de Cologne.

(5.) *In the conduct of Chemical Operations, life has been lost owing to the accidental or unsuspected presence of arsenic in the materials employed.*

Danger to life and loss of life have frequently occurred in the conduct of chemical operations, through the accidental presence of arsenic in vapour. This fact is well known to Toxicologists. Indeed it is because that some of the best authenticated cases are those of professional chemists, that the facts have been so well ascertained. I will cite a few instances. Thus Gehlen,† Professor of Chemistry at Munich, while preparing hydrogen, suspected a leakage in the tubes of his apparatus, and testing the matter by smelling, he inhaled a very small quantity of arseniuretted hydrogen. An hour after he

* Chemistry of Arts and Manufactures, vol. ii., p. 1023.

† Annales de Physique et de Chemie, tome xc., p. 110.

was seized with vomiting and pains of stomach, followed by great prostration of strength, and he died miserably on the ninth day. Mr. Brittan, a chemist in Dublin, was experimenting on hydrogen, with the view of determining its effects on the voice, and he inhaled about 150 cubic inches of what proved to contain arseniuretted hydrogen generated from arsenic, which, without suspicion on his part, was contained in the sulphuric acid he employed. He was soon after seized with continuous vomiting, pains of stomach, and great prostration of strength. He died on the eighth day, and arsenic was found in the tissues of the body. Dr. O'Reilly,* Lecturer on Medical Jurisprudence, who narrates the case, tells us that on sending to six respectable drug shops in succession, for samples of sulphuric acid, he found every specimen largely charged with arsenic. He also made a quantitative analysis of the acid employed by Mr. Brittan, and from the particulars he gives of a rather crude experiment very confusedly expressed, I infer that he found 4 grains of sulphide of arsenic in 200 grains of the sulphuric acid, a proportion that exceeds 13 lbs. of arsenious acid to the ton of sulphuric acid, assuming normal specific gravity and fluid measurement. Dr. O'Reilly refers in his communication to another fatal case—that of Beard, a young English lecturer on chemistry, but he gives no particulars. Gmelin† quotes the case of Bullacke, a chemist, who accidentally inhaled arseniuretted hydrogen, and after suffering the usual symptoms, died on the twelfth day. Dr. Taylor‡ narrates the case of a young gentleman who accidently respired a small quantity of arseniuretted hydrogen from a mixture of arsenic, zinc, and sulphuric acid, and who died twenty-four days after the accident. Professor Robertson,§ of Calcutta Medical College, while delivering a lecture on arsenic, unwittingly breathed a portion of this gas, which was accidentally escaping from a Marsh's apparatus, while a current of air chanced to direct the gas towards Dr. Robertson. He was soon after seized with sickness, continuous vomiting, pain of stomach, and great prostration of strength, with other characteristic symptoms of a dangerous nature, and which were more or less present in the other cases referred to, and he did not recover until the twenty-second day. M. Ollivier‖ describes the case of a young French chemist, B——, in whose laboratory a quantity of arseniuretted hydrogen had been accidentally set free, and had become diffused through the apartment. Sickness and continuous vomiting began within an hour afterwards, and were followed by alarming debility. He was conveyed to M. Piorry's Wards at La Charitè, where he died on the fifth day. Sir R. Christison ¶ referring to cases of poisoning by arsenic which had occurred owing to the adulteration of sulphuric acid with arsenic,

* Dublin Medical Journal, 1842, p. 442.
† Handbook of Chemistry, vol. 4, p. 265.
‡ Taylor on Poisons, p. 442.
§ Cheever's Jurisprudence for India, 1870, p. 833.
‖ Gazette Medicale de Paris, 1863, vol. 18, p. 704.
¶ Christison on Poisons, 4th edit., 1845, p. 288.

quotes a case related by Dr. Schlinders of Graefenberg, which did not prove fatal, but in which the symptoms of poisoning continued until the seventh week. Mr. H. Watson,* in illustration of the dangerous consequences which may result from ignorance of the arsenical contamination of pyrites sulphuric acid, adduces the case of a workman in his neighbourhood who was nearly killed by inhaling arseniuretted hydrogen generated from dilute arseniferous sulphuric acid acting upon an iron retort. Dr. Guy † quotes a very interesting series of cases occurring under the observation of Dr. Elliotson, where poisoning by arseniuretted hydrogen affected a whole family, the gas having been evolved from decomposing arsenite of copper. I might vary these illustrations from what is recorded of the effects of arsenical contaminations of the atmosphere, proceeding from wall papers or wax candles, &c. The dangerous potency of these has been often impressed on the public mind by various observers, and among others by Dr. Macadam of Edinburgh. But I have said enough to show that there are known conditions in which arsenic may be accidentally present in the atmosphere in its most deadly form, that of vapour.

(6.) *In the manufacture of Bone Manure there are given off vapours impregnated with arsenic derived from the sulphuric acid employed in the process.*

Hitherto the most familiar illustrations of the hurtful effects of arsenical vapours have been furnished by arseniuretted hydrogen. But there are other equally deadly forms under which arsenic can be volatilised. And I have now to show that there exists on a very large scale a set of such conditions in the manufacture of artificial manures, a branch of national industry of great and increasing importance. As this industry is not yet under State supervision, there is much difficulty in reaching correct data, but from a reliable trade list of chemical manufacturers, I have satisfied myself that there are *not less* than 25 artificial manure works in Scotland, 67 in England, and 12 in Ireland. As regards the total quantity of artificial manures produced in Great Britain, I am informed by Dr. Angus Smith, on the authority of Mr. Lawes, whose name is identified with the manufacture, that the probable quantity will not be less than 500,000 tons annually, and from other sources of information I think this a safe and moderate, if not an under, estimate. From the Board of Trade returns, I observe that in 1873 there was *exported* from the country artificial manures to the value of £671,550.

In the manufacture of artificial manure, bones form the essential constituent; and there are imported annually upwards of 100,000 tons of bones from South America, Egypt, Russia, &c., all employed in the production of Bone Manure, in addition to at least an equal quantity

* London Medical Gazette, Feb. 19, 1841.

† Guy's Forensic Medicine, p. 470.

of home produce.* Mineral phosphates are also much used, the largest supplies of which consist of coprolites, a kind of fossilised excrement of Saurian reptiles. Of these phosphates, under various names as "Charleston mineral," and of "Canadian phosphate," a kind of Apatite, there are upwards of 50,000 tons imported annually,† irrespective of large quantities found in this country in the chalk formation, together with other phosphatic mineral deposits rich in the desired phosphate of lime, and all largely used for agricultural purposes.

Sulphuric acid is the dissolving agent throughout the varieties of artificial manure manufacture, but as the proportion of carbonate of lime differs considerably in these mineral phosphates, it cannot be stated definitely what amount of acid should be used in every variety. At one time, bones are only exposed to the action of the acid; at another, a mixture of bones and of mineral phosphates, or of the latter only. The foremost modern authority in connection with agricultural chemistry, is Dr. Voelcker, Consulting Chemist to the Royal Agricultural Society of England, and he obligingly informs me that "with regard to the proportions of sulphuric acid employed for "100 tons of manure, I would observe that for the production of "100 tons of manure, as an average, from 40 to 45 tons of chamber acid are required." From this data I estimate that in the production of 500,000 tons of artificial manure, there are employed 212,500 tons of chamber acid. This is therefore a large branch of the national industry. With such quantities of material to be manipulated, we are carried quite beyond the region of laboratory operations or accidents, and reach the domains of general interests and public hygiene.

Having had frequent occasion to witness the manufacture of artificial manures in various factories, to advise in the construction and modification of works, and to make enquiries regarding their alleged or probable effects on the health of workers and of others exposed to their influence, I have, as a result of these experiences, been long impressed with a conviction that in the course of the operations conducted at these works, there was a liability to the production of stronger effects than merely disagreeable "smells." I have expressed these convictions in that division of the present memoir which forms an appendix to my "Report on a Manure Work." I have there endeavoured to point out the distinction which in my opinion should, wherever possible, be drawn between vapours or gases of known chemical composition, and organic exhalations of unknown character or composition—between "chemical poisons" and "animal poisons." In the vapours disengaged from manure works, I am satisfied that we have a combination of both kinds, viz., of chemical gases, and of animal miasms. And I admit that it is with a certain bias of conviction that I have attempted to

* Simmond's Waste Products, 1873, p. 90.

† Kensington Museum Catalogue of Waste Products, &c., 1875, p. 63.

solve the question, whether there did, or could exist anything in these manure vapours that was more likely to account for such instances of apparent injury from their effects as I had observed, than the hackneyed explanations of bad "smells," "effects of imagination," or exaggerated sensitiveness to smells," &c. Many years back, viz., in 1863, when engaged with the late Dr. Penny and the late Dr. Anderson in preparing evidence in connection with a "manure nuisance" litigation, I had fixed upon the arsenic in sulphuric acid as a possible element of danger. I mooted my idea to both of these gentlemen, but their opinion given off-hand, and as I can now see, without any real consideration of the question, was adverse. I was therefore diverted from making any experimental observations. But when retained to give evidence in the recent case at Inverness, I carefully reflected on the added experience and information I had gained in the interval, and my interest in my old problem was revived. All the more was I stimulated to make a special investigation, when I learned from the precognitions already taken, that the evidence was likely to be restricted to the usual routine jog-trot questions of "smells,"—of "offensive smells,"—of "how far these smells" had been perceived or could be carried, &c., &c. I thought it would be of no use to broach my hypothesis in a speculative manner to any chemist, and I therefore made some simple experiments myself. These were to me surprisingly conclusive. I then approached with confidence several professional chemists with whom I am on cordial relations, and in every instance, although my idea was regarded as novel, and in more than one case as very doubtful, there was nevertheless a previous satisfactory knowledge of the usual arsenical contamination of commercial sulphuric acid. The fact that Glasgow chemists live in a centre of large chemical manufactories, and can any day, within a five minutes journey, see the materials and the process of manufacturing sulphuric acid, and can obtain for the asking any amount of samples, naturally gives them a practical familiarity with the elements of my problem, which can not fairly be expected from others less favourably situated, even if theoretically well informed. In Edinburgh it has been shown that a professional chemist may not be able, even in urgent circumstances, to lay his hand upon a sample of this, the most extensively produced and most familiarly employed article of chemical manufacture. I found also in Glasgow chemists such a knowledge of the numerous and complicated re-actions of which arsenic is susceptible, that it was only required to ask their serious consideration, and the probable truth of my theory was at once admitted. Indeed, in the instance of Professor Dittmar, that gentleman after a few minutes reflection promptly said to me, "I would not be at all surprised to "find arsenic given off in the vapours from bones treated with pyrites "acid. On the contrary, I would be much surprised if arsenic was "*not* given off." Each and all recognised that the question was of public importance, and cordially lent their aid in making such experimental trials as I suggested. It is to a merely representative selection of these experiments, in something approaching to their chronological order, that I now direct attention.

To confirm my own preliminary experiments, I applied in the first instance to my friend, Mr. Tatlock, and without reference to the case in which I was engaged, or the object I was pursuing, I left a verbal message with his assistant, simply requesting that he would make an experiment for me, imitating the manufacture of bone manure, using common sulphuric acid, and testing for arsenic in the vapours given off. Three days afterwards I received the following letter :—

Letter from ROBERT R. TATLOCK, F.R.S.E., F.C.S., *Lecturer on Chemistry, and Public Analyst for Glasgow, &c.*

22nd February, 1876.

DEAR SIR,—I have made the experiment with the object of ascertaining whether arsenic is given off during the dissolving of bones by pyrites vitriol.

The mode of operating was as follows :—The bone received from you was broken down to quarter inch size, placed in a retort and treated with rather more than half its weight of sulphuric acid, which had been previously made down by mixing two parts of the acid of 1·7 sp. gr. with one part of water. The retort was connected to a set of potash bulbs containing a little water, and these again were connected with an aspirator by which any arsenical vapours coming off would be drawn through the water in the potash bulbs, and there retained for testing. On applying Reinsch's test to the latter, *the result was that arsenic could be easily detected in the fluid*, although present in small quantity. I do not know in what form the arsenic comes off. I think it is probable, however that it must have been as fluoride, although I have never heard this suggested.

I remain, yours faithfully,

ROBERT R. TATLOCK.

In imitation of the chemical action which occurs when bone manure is made on the large scale, Mr. Tatlock properly applied heat during the experiment, keeping it under 212° F. Large masses of material, such as are employed in the manure factory, retain for many days the great heat developed within them by chemical action. Small quantities of material get quickly cooled, and therefore in a laboratory experiment artificial heat is applied to prevent this premature cooling, and thus to preserve the same condition of things that exist in the practical manufacture. I have not ascertained the extreme degree of heat produced by the action of dilute acid upon crushed bones. It is known, however, that a mere mixture of concentrated sulphuric acid and water evolves a heat of fully 300° F. By experiment in a manure factory I have ascertained that the heat within the mixing box exceeds 240° F. within 3 or 4 minutes after the acid is added to the bones. After the dissolving bones are discharged into the "receiving pit," it is very probable that a much greater heat is produced ; but this is a point very difficult, and, as I have personally experienced, very dangerous to determine, if attempted in an off-hand manner. But in the heaped manure which had remained undisturbed for three or four days after it left the mixing box, I found a heat exceeding 210° F., and in another heap which had been exposed to the cooling action of a fanning machine for 16 hours, I found a heat of 180° F.

As during the ten years that Mr. Tatlock was senior assistant to the late Dr. Penny, I had worked with him in various important investigations, and knew that a reliance was placed upon him that needed no after verification, I felt boldly confident, and set myself to obtain such additional corroboration as might be requisite to meet sceptical after-enquirers, or to vary the illustrations.

My friend, Mr. "N. R.," a promising young professional chemist, has special facilities in connection with one of the oldest established manure works in Scotland. He was the next to whom I applied, and he sent me the following notes of the experiment he made at my request:—

"I treated the bones with dilute chamber acid, and condensed the gases which were given off in water.

"Then treated a portion of the solution of gases in water with sulphuretted hydrogen; result, a yellow precipitate soluble in ammonia and re-precipitated with hydrochloric acid, indicating presence of arsenic.

"To another portion of the solution of gases in water I added nitrate of silver, which gave a yellow precipitate soluble in ammonia and re-precipitated by nitric acid, indicating presence of arsenic.

"There is also hydrofluoric acid given off, corroding largely the neck of the retort, which may combine with the arsenic, but the bulk of the arsenic is, I think, given off as chloride."

At this time I chanced to be engaged in another case of a somewhat similar character, with Dr. Machattie, Consulting Chemist, who for some time was proprietor of a vitriol work, and was necessarily very familiar with the practical questions relating to the various qualities of acid. I sought his aid, and he found that the fact I was seeking to test, was "very easily verified." He made several experiments, of which the following is an example:—

"Acid of 1·58 sp. gr. made from Spanish pyrites was slightly diluted with water and added in the usual proportion to crushed bones, and treated in a retort, heated in imitation of the heat evolved when the materials are manipulated in bulk. The gaseous exhalations were conducted into a jar containing caustic potash in solution. This jar was closely corked, but a glass tube conveyed from the upper part of the jar any vapour which might escape condensation or decomposition in the potash, and conveyed it into a solution of nitrate of silver. The result was that arsenic was found easily in the caustic potash, but none in the solution of silver."

In Dr. Machattie's after experiments, made in my presence, the gases were simply condensed in water. Pure hydrochloric acid was added to the distillate, which was then treated in a porcelain capsule and pure copper-foil applied, with the result that strip after strip of the copper got coated with arsenic "until the process became tedious." One experiment we made was with sulphuric acid, bones, and bone-ash, obtained by me from the Bunchrew works on the occasion of my second visit, and the results were precisely similar to those in the other trials.

As there was now abundant proof that arsenic *in some shape* was evolved from bone manure, I became interested in the farther enquiry as to the exact form or the various combinations in which it might be disengaged. Chloride and fluoride were indicated, but I suspected that arseniuretted hydrogen would also come off where the acid is weak and where the bones are stirred up in an iron vessel with an iron screw, because iron, although not so effective as zinc in generating hydrogen, is, nevertheless, capable of doing so. About this time I also obtained a crucial confirmation that lifted the question out of the circle of mere laboratory experiments or theoretical disquisitions.

On the occasion of my first visit to Bunchrew works, I had observed that the ceiling and walls of the mixing pit were encrusted all over with a greyish looking material, which was evidently a condensation of the vapours disengaged in the pit from the dissolving bones. I had observed the same elsewhere and surmised its probable composition. On my second visit, while on my way to the work, I requested the attention of my companions, Drs. Mackay, Littlejohn, Dunlop, and Mr. Archer, to the appearance we would meet, and in their presence one of the workmen, under the instructions of his employer, also present, removed a sample and gave it to me. I am thus precise in narrating a seemingly trivial matter, because a gentleman who had visited the place a few days previously deponed that he did not see any of this encrustation. Neither had the proprietor nor his workmen seen this encrustation until I pointed to its deep and thick layers adhering to the walls and roof, and as evident as soot in a chimney. The incident illustrates the small value of negative evidence, and the distinction that exists between seeing and *perceiving*. It is illustrated in every day life. We walk through the streets and do not perceive our most familiar friends because we are not looking for them, and because our thoughts may be elsewhere. A detective singles from a crowd the man who is "wanted," because he is looking and is intent on his object. I was looking. The gentleman who did not see this encrustation very naturally did "not expect" that there would be found in it what I found.* I know so

* A paper on "Chloride of Arsenic," written conjointly by my friends, *Dr. Wallace* of this city, and the late Dr. Penny, and published by them in the Philosophical Magazine for November, 1852, directs the attention of chemists to "*the extreme facility with which chloride of arsenic is formed and volatilised* when arsenious acid is heated with hydrochloric acid;" and they state that they have been impelled the more to their investigations because that "*its invariable formation* by heat in presence of hydrochloric acid has, we think, been frequently overlooked," while, as regards its volatility, they point to "the fact that the chloride

much of him as to feel well assured he would have seen and found all that I did if he had happened to be looking. On examination, this encrustation or deposit of condensed gases was found to be charged with arsenic. I followed up a clue so important, and procured from another manure work a sample of vapours condensed by a special arrangement for preventing their escape, and which are collected several hundred feet distant from the spot at which they are disengaged. This deposit also contained arsenic, and I have since obtained and examined numerous other samples with like results. These samples vary a little in colour, in the quantity of water associated, and in the amount of arsenic they contain. With one exception, every chemist to whom I have given portions of this material have found it to contain arsenic in very appreciable quantity. Elsewhere I have shown quantities. So little of difficulty is there in the matter that Mr. Clerk, the able and painstaking assistant of Professor Mills, tells me that one of his students proved arsenic easily in a small sample issued to him as an ordinary laboratory exercise. And I saw a pupil of Professor Dittmar, a mere lad, make an excellent quantitative analysis, and he handed over to me the arsenic he had extracted. But the detection of arsenic in the vapours of bone manure, or the extraction of arsenic from a complex material is *a process* that requires time. It is not a matter to be resolved by a simple test like that of dipping litmus paper into a fluid, to determine the mere fact of acidity. It cannot be done offhand during the breakfast hour. No chemist who verified the facts on which I am commenting was able to compress any reliable experiment under three days. May not these considerations explain why it was that Dr. Macadam's experiments proved negative. He had not sufficient time between twelve o'clock at night and ten o'clock next morning to do himself and the subject proper justice.*

distils freely at a temperature very much below its point of ebullition." And, "as the formation and escape of chloride of arsenic appears therefore *to occur with certainty* when arsenious and hydrochloric acid are heated together, it becomes interesting to enquire whether similar results would obtain *in presence of organic matters.*" They then detail experiments with such organic matters as cow's liver, broth, oatmeal porridge, &c., in all which "the results were equally satisfactory," &c. In the treating of bones with arsenical sulphuric acid, we have *the precise conditions indicated in the paper*, viz., arsenious acid heated with hydrochloric acid in presence of organic matters; and therefore it is precisely in such a place as the mixing pit of a manure factory that a chemist who had read Wallace and Penny's memoir *would expect* to find the encrustation referred to. It is very evident, therefore, that the chemical witness—who said that "he had seen no encrustation on the walls of the building, and even if there was, he would not expect to find arsenic in such encrustation"—could not have retained a very lively recollection of the excellent experiments he had witnessed, by means of which Messrs. Wallace and Penny very clearly demonstrated facts that are too "frequently overlooked."

* Let me illustrate this point for the information of individuals who may not be versed in chemical processes, for it is important. Here is one method of analysis pursued by the different chemists in dealing with the "encrustation" and deposits referred to. The material was treated with *boiling* water; then

The quantity of these gases at manure works is not that of chemists' "traces" but that of manufacturers' "waste products." These "condensed gases" consist of tangible, visible, ponderable matter, collected and removed at stated intervals *by the ton,* in one of the works where the special arrangements exist to which I have referred. There is therefore no lack of the material for other experiments. The proprietor of this work—which, by the way, I may state is the most intelligently constructed and conducted work of which I have knowledge—promises me that any professional chemist presenting my card will be permitted "to carry away as much of these condensed gases as he can remove, and if aided by a horse and cart so much the more welcome."

This was the state of my information at the date when Counsel were constrained to the resolution of "dropping the arsenic theory." I have since widened the enquiry and varied the illustrations of proof. Chemists of high responsible status have favoured me, for publication, with a record under their own hand of the scrupulously careful observations they have made, in the full knowledge that they were dealing with a vexed question, which was only to be determined by reaching the bare truth. And if I do not more warmly express my sense of personal obligation, it is because I know that they themselves desire to be regarded not as partisans but merely as labourers in the cause of science.

Hitherto I have spoken of artificial manure as if it involved no consideration of other materials than bones, coprolites, and sulphuric acid. But in many factories where other materials are readily available, there are also employed blood and flesh of animals, leather cuttings, hair, wool, feathers, soot, spent animal charcoal of sugar refiners, &c., &c. But careful consideration has satisfied me that when they are employed as a mere adjunct to the staple materials of bones and mineral phosphates, there can be little of practical difference in the character of the gaseous products evolved by the action of sulphuric acid. In bone manure manufacture arsenic seems to be disengaged in three forms, viz., chloride, fluoride, and arseniuretted

neutralised with ammonia, and an excess of yellow sulphide of ammonium added to it; then boiled again for a short time; frequently shaken up; then allowed to stand over night in a moderately warm temperature. On the following day the material was filtered off; then acidified with pure hydrochloric acid, and again allowed to stand over night in a moderately warm place. On the third day the precipitate which had been formed was freed by filtration, and treated with dilute ammonia to separate the arsenic from the bulk of the antimony. The filtrate, which contained sulphide of arsenic, was then evaporated to dryness; the residue dissolved in fuming nitric acid, and evaporated with addition of a little sulphuric acid until sulphuric acid began to come off. After cooling, the liquor was diluted with water, and the solution treated in Marsh's apparatus.

This experiment, the operations of which are so succinctly described, occupies three entire days, in which there is not one hour of wasted time. The two separate samples of "encrustation" and of "condensed gases" handed to Dr. Macadam at near midnight had been examined and were pronounced upon next morning!

hydrogen, and very much in the order enumerated. Indeed, if the chlorine and fluorine and silicic acid contained in the ingredients could be accurately determined, it would be possible to estimate pretty closely the amount of arsenic given off. For it may be assumed that most of the chlorine and available fluorine will be given off in combination with their equivalents of arsenic, owing to their affinity and the favouring conditions for effecting combination which the manure manufacturing process affords. It is impracticable, however, to get a correct average of the amount of chlorine and of fluorine contained in bones, owing to the varied conditions in which they are employed in the making of manure. Sometimes there is a large proportion of "green bones," with cartilaginous and ligamentous attachments and other associated organic matter. In this condition the chlorides will be abundant. Sometimes the bones have been much "weathered," and then all estimate is confused. Sometimes there is a large proportion of fossil bones, and then the fluorine will be large.* But a general notion that the quantity of these combining elements is considerable may be gathered from a study of the elaborate analyses given in Simon's Animal Chemistry and Lehman's Physiological Chemistry, &c. From an examination of 21 analyses I find that in clean dry bones the chlorides amount to mor than $1\frac{1}{2}$ per cent.; and in the associated organic matter of cartilage to nearly 10 per cent. In dry blood the chlorides are 10 per cent., and in dry flesh 2 per cent. The fluoride of calcium in bones varies from 1 to 4 per cent., although in fossil bones it may be found as high as 17 per cent. In the bones of oxen and sheep, according to Heintz, it averages nearly 3 per cent. In the teeth fluoride of calcium exists very largely. So much for the staple animal matter of artificial manure. With regard to the mineral phosphates, the fluorine is subject to considerable variation, one sample yielding only 1 per cent., and another ten times as much. Dr. Voelcker gives two analyses of Cambridge coprolites, each showing 5 per cent. of *fluorine*, equal to double that amount of fluoride of calcium. His examination of coprolites has been more extended than that of any observer of whom I have knowledge, and as this point of the proportion of fluorine is of considerable importance, I applied to him for information. He obligingly informs me that "a fair average of all kinds of coprolites will give about $2\frac{1}{2}$ per cent. of *fluorine*."

There exists therefore in the staple constituents of bone manure a large amount of those elements that form volatile compounds of arsenic, viz., *chlorine, fluorine, arsenic, iron, and sulphuric acid.* The implements employed usually consist of *iron*, as in the mixing box

* In phosphorites, coprolites, and fossil bones, the quantity of this constituent, as a rule, amounts to several per cents.; a fossil bone analysed by Baumert contained 17 per cent. of CaF^2. The bones of all vertebrates contain small quantities of fluoride of calcium. *Qualitative Chemical Analysis* by W. Dittmar, Edin., 1876, p. 28.

and paddles. Therefore, from the decomposition of these elements when brought into relation, there is necessarily disengaged, according to theoretical considerations :—

a. Volatile chloride of arsenic.
b. „ fluoride do.
c. „ arseniuretted hydrogen.

These theoretical assumptions are practically demonstrated in the following communication from my friend Mr. "M.," who, having sufficiently verified the simpler points of the general problem, determined on a synthetical investigation in which the elements presumably entering into combination were treated *seriatim et singulatim.*

GLASGOW, 20th April, 1876.

My Dear Sir,

I am surprised at your communication to the effect that there is a gentleman who holds, after careful theoretical considerations, that it is an impossibility that arsenic should be given off during, or after the process of manure making; and who has persuaded himself that he had established by experiment beyond the slightest doubt, that any arsenic which might perhaps be present in the sulphuric acid used, remained actually and entirely in the manure. My surprise is in no way lessened when I hear that the same gentleman has failed to detect arsenic in the very samples from which I had previously extracted that metal, small specimens of which I handed over to you.

In the face of all this, allow me to express my doubt whether these statements proceed from a practical chemist, as I think it impossible that a professional man could arrive at either practical or theoretical conclusions like these, after only one moment of reflection about all the circumstances which attend the manufacture of manures. However, there may be chemists and chemists.

Regarding that gentleman's experiments, and his analysis of the deposits in question, I, of course, have to believe him when he says that he failed to find arsenic.

As far as I am concerned, I was satisfied as soon as you mentioned the subject to me, that arsenic *must* be given off during the making of manure. It seems really curious that no chemist or sanitary physician should previously have investigated a problem so important, so clearly evident when attention is drawn to the subject, and so easily capable of conclusive proof; for you are, as far as I am aware, the first who took the probability of arsenic being given off into consideration.

Although you have been present at many of the experiments I made regarding this subject, I will describe shortly some of them.

The first material which I received from you for examination was a deposit which had been taken from the walls of a manure chamber at a manure work near Inverness. I undertook a little qualitative analysis and found that it contained silicon, fluorine, arsenic, and antimony, amongst other inorganic and organic bodies. The arsenic was extracted by well-known methods, and a little specimen of a mirror of arsenic which was obtained from this substance in Marsh's apparatus, you have in your possession.*

* Mr. "M." has since made several qualitative examinations of different samples of this deposit of condensed gases. And in particular he has made a very careful quantitative estimate of the arsenic contained in a portion of the same sample I exhibited at Edinburgh. The following is a summary of this analysis.

Arsenious acid in moist deposit, . . 0·119°/₀ which is equal to
Do. do. in deposit when dried at 118° C. 0·497°/₀
Deposit loses when dried at 118° C. . . 76·14°/₀

The quantity of arsenious acid in One ton of moist deposit is= 2 lbs. 10 oz. 284 grs.
Do. do. do. dry do. =11 lbs. 2 oz. 55 grs.

Mr. M. placed in my hands a variety of specimens of arsenical mirrors of metallic arsenic, of arsenious acid and of arseniate of ammonia and magnesia, produced from sulphuric acid, from deposits of condensed gases, from manure vapours containing chloride of arsenic, arseniuretted hydrogen, &c., &c.

The second material you gave me was the so-called "condensed gases" collected at a manure work near Glasgow, in a flue several hundred feet from the manure chamber. This specimen also contained silicon, fluorine, arsenic, and antimony, &c. You have mirrors of the arsenic which was extracted from this stuff.

There is no doubt that this arsenic is derived from the sulphuric acid employed for manure making, which contains it as arsenious or arsenic acid or in both states of combination; and anybody at all acquainted with sulphuric acid making will know how it came there.

The question remaining is how the arsenic goes off; and here the facility with which arsenic enters into combination with chlorine, fluorine, and hydrogen, and the volatility of the products are too well known to need comment.

Other experiments made upon your suggestion in imitation of the process of manure making on a large scale, proved that the detection of arsenic in the vapours which are given off is such an easy matter that the presence of that metal can be demonstrated by comparatively inexperienced chemists. I therefore turned my attention to some other points.

If there is enough chlorine to volatilise the whole of the arsenic, then the presence of a larger or smaller quantity of fluorine is of no consequence as far as arsenic is concerned. Should, however, the chlorine not be sufficient to carry off the whole of the arsenic, then the capability of the fluorine to do so becomes of importance. In making the qualitative analysis of the deposit referred to above, I was struck with the large proportion of silicic acid contained therein, and finding besides a considerable quantity of antimony, both these facts seemed to point to chlorine as the element which helped to carry the arsenic and antimony over.

I therefore made the following experiment:—

Suphuric acid (pure) of 1·60 sp. gr. was so adulterated with arsenic that it contained 0·0748 per cent. of arsenic as arsenious,—and 0·0774 per cent. of arsenic in the form of arsenic acid. To this arsenical sulphuric acid there was added a quantity of fluor spar sufficient to convert about two-thirds of the arsenic into fluoride of arsenic, and of silicic acid in the form of a fine powder, in excess to that which the fluorine required in order to form silicon fluoride. On being heated, whilst a stream of carbonic acid was passed through the retort in order to carry off the vapours more easily, the white fumes of hydrofluosilicic acid were at once visible. The temperature of the liquid was kept for some time between 150° and 160° C., but the distillate contained no arsenic. A new quantity of fluor spar and silicic acid in the same proportions as at first was now added, and also a little chloride of sodium, while the temperature was reduced to 130° C. White fumes instantly appeared, and the first drops of liquor which came over contained a large quantity of arsenic, whilst the distillate which was collected about fifteen minutes afterwards was nearly free from arsenic. In this case fluorine having a greater affinity for silicon than for arsenic had first carried over silicon in the form of hydrofluosilicic acid. The power of the fluorine present, to carry over arsenic was kept in check so long as any silicon was present with which the fluorine could combine. Then chlorine in the form of chloride of sodium was added, and the chlorine took over arsenic as chloride of arsenic. After this the distillate showed that no arsenic was coming over; but if there had now been added more fluorine than the silicon could have taken up, that excess would have volatilised arsenic, which would have gone over as fluoride. This shows, therefore, that so long as silicic acid is present it interferes with, and is a preventative of, the volatilisation of arsenic by fluorine.

Another very important point relates to the production of arseniuretted hydrogen, where iron vessels are used for mixing bones and sulphuric acid. That this is a matter not to be lightly dealt with will become evident when it is considered (1st) that the oxygen compounds of nitrogen which exist in sulphuric acid are easily decomposed; (2nd) that *sulphuric acid becomes weaker* during the mixing process, because that the gypsum (sulphate of lime) which is formed cannot take up its water of combination so long as the high temperature existing during the process exceeds about 120° C.; and (3rd) that dilute sulphuric acid acting upon iron gives off hydrogen. Therefore, during the "mixing process" of manure manufacture, and when the materials are at an elevated temperature, and when iron is present, there is liable to be disengaged arseniuretted hydrogen.

To show that arseniuretted hydrogen is actually given off *at elevated temperatures*, 10 parts of water and 8 parts (fluid measurement) of pure concentrated sulphuric acid were mixed together, and the mixture used for the following experiments :—

A quantity of this dilute acid was so adulterated with arsenious acid as to contain about 0·07°/₀ of arsenic, and heated in contact with metallic iron to about 135° C. The gases produced were carried off by means of a stream of pure hydrogen, and were found to contain arsenic.

Another quantity of the dilute acid was adulterated with exactly the same amount of arsenic in the form of arsenic acid, the latter containing nitric acid. The first action of this mixture upon metallic iron was an evolution of red fumes. This, however soon ceased, and the gaseous products of the further action (at 135° C.) were also proved to contain arseniuretted hydrogen.*

In order to obtain mirrors of arsenic, these experiments were repeated, but with a more dilute acid. The mixture employed was 2 parts (fluid measurement) of pure concentrated sulphuric acid, and 3 parts of water. The mixture boiled at 124–125°/₀C. One portion of this mixture was so adulterated with pure arsenious—and another portion with pure arsenic—acid, that in both cases the quantity of arsenic was below 0·1°/₀.

The experiments were conducted at a temperature of 120 to 122° C. The gases produced in contact with iron were carried out of the apparatus by a stream of pure hydrogen, and after being freed from sulphuretted hydrogen and aqueous vapours, used for the direct production of the mirrors of arsenic which have been given to you.

It may be stated that arsenic acid produces arseniuretted hydrogen more readily and completely than arsenious acid.

It might perhaps be worth investigating whether some material might be found, which having, under these circumstances, a greater affinity for chlorine than arsenic, would prevent the formation of chloride of arsenic.

I remain, my Dear Sir,

Yours very truly,

"M."

In all the experiments hitherto made I had supplied the bones in a fresh state from my own kitchen. It occurred to me that there might be some modification of the results if bones were employed which had been long exposed to the atmosphere, and otherwise worn and decayed, or "weathered," as such bones are termed in technical phrase. In this condition I could only expect *minimum* results. I accordingly procured samples from two manure works of "¼-inch bones," which had travelled far and been much "weathered." One sample, which turned out to be of extremely poor quality, I gave to Professor Mills; and of the others I gave one sample to Professor

* I saw Mr. "M." make two experiments with bones, arsenical sulphuric acid, and iron wire. In both instances arseniuretted hydrogen was given off, from which it was evident that the acid had become sufficiently dilute to act upon the iron. There are two sources from which the action of iron may be expected in the preparation of superphosphates. *First*, the iron mixing box usually employed. *Second*, fragments of scrap iron which are bought up by dealers in bones. A manufacturer tells me he has frequently seen several pounds weight of iron in a parcel of bones not exceeding a hundredweight, and that it is often added to increase the weight. J. A.

Dittmar, and one to Dr. Milne. In addition to the essential facts I was seeking to corroborate, I directed the attention of these gentlemen to the behaviour of artificial manure after it has undergone the first or mixing process, and has been removed from the mixing pit to the stores, where it is subject to be frequently turned over and broken up, riddled through sieves, dried in stoves or on hot plates, and occasionally treated with chemical agents, or additional substances technically called "driers." More or less of these processes are in use according to the usages and appliances of various factories, before the material is finally fit for sale. During the entire period it is giving off a strong odour, vapours are sensibly exhaling, a heat considerably greater than the temperature of the atmosphere is present, and chemical action is going on actively. It therefore seemed to me probable that the evolution of arsenic was not confined to the first stage of the manufacture, and that a residuum of pent up chlorides and fluorides might get disengaged during the manipulations referred to. Moreover, I was strongly of opinion that the chemical re-actions which volatilised the arsenic were so certain that they would occur even although the stimulating conditions of heat were withheld. I therefore suggested an "air experiment" to determine this very important point. How these and other views already discussed were illustrated will now be shown in the communications which follow, and which I give in the order of their dates, commencing with the clear, short, and yet thoroughly comprehensive demonstration of the professor of scientific chemistry in Anderson's University.

Letter from W. DITTMAR, F.R.S.E., &c., *Professor of Chemistry in Andersonian University.*

Andersonian University,
Glasgow, April 8th, 1876.

James Adams, Esq., M.D.,

Dear Sir,

Having completed the experiments which I promised to carry out with the specimens you placed into my hands some time ago, I now beg in the following report to submit to you my results.

I have examined the contents of the bottle labelled "condensed vapours" for arsenic, and, using five grammes of the material, had no difficulty in proving the presence of this element by means of Marsh's apparatus.

I have also, in accordance with your request, made an experiment on your sample of *superphosphate* [prepared from bones], with a view of seeing whether this preparation, when freely exposed to the atmosphere,* would give up to it *appreciable quantities of arsenical vapours*. For this purpose 500 grammes of the substance were placed in a bottle lying horizontally on a table, and there was drawn over it, by means of an aspirator, a current of air, which, after having swept over the superphosphate, was next filtered through cotton wool, and then made to pass through a slanting absorption tube about one yard long,

* While passing this sheet through the press, I have accidentally learned that this sample of superphosphate had already been "freely exposed to the atmosphere" through the action of a special drying apparatus in the manure factory. It is therefore surprising that the experiment was not altogether abortive.
J. A.

and charged with a solution of 5 grammes of pure caustic soda in 120 grammes of water. The current of air was kept up day and night for ten days. The contents of the absorption tube were then acidified with pure sulphuric acid, concentrated by evaporation, and examined in Marsh's apparatus. There resulted an extremely faint but nevertheless *distinct mirror of arsenic.*

I will now pass to the experiments which I made with your samples of "*Charleston mineral*" (which I understand to be a species of coprolites), and of "crushed bones," with the object of enabling you to form at least an idea of the extent to which the manufacture of these materials of *superphosphate* by means of arseniferous sulphuric acid could lead to the contamination of the atmosphere with arsenical vapours.

In the customary process of superphosphate making the acid is used in the form of "*chamber acid*" (*i.e.*, as an aqueous solution, containing about 60 per cent. of real acid) which being always produced from *pyrites*, must in general be assumed to contain more or less of arsenic.

Now it is known by experience that arseniferous chamber acid, when concentrated by evaporation, even to the state of "*oil of vitriol*," gives off vapours which are *free* from arsenic. Hence, in the manufacture of superphosphate, if arsenic is volatilised at all, it can be volatilised only in the form of *fluoride* or *chloride* formed by the conjoint action on the arsenious oxide of the sulphuric acid, and of the fluorides or chlorides in the "*phosphate*." These considerations formed the basis of my mode of investigation.

I first prepared from pure materials an artificial "chamber acid" of about 60 per cent., which was completely saturated in the cold with arsenious oxide. A weighed quantity of each of the two materials was mixed in a glass retort, with enough of the arseniferous acid to convert the *whole* of the lime present into sulphate (*i.e.*, with considerably more than is used in practice), and the mixture distilled to dryness. From the distillates, which both contained arsenic, this metal was eliminated and quantitatively determined.

The results were as follows:—

"Charleston mineral" (or coprolites). Quantity operated upon—100 grammes. The vapours strongly attacked the glass of the retort. The distillate gave, with sulphuretted hydrogen, a precipitate of sulphide of arsenic. The sulphide was converted into arseniate of ammonia and magnesia. This precipitate, after having been dried at 103 C., weighed 0·0812 grammes—equal to 0·0424 of $As_2\ O_3$—equal to 15·2 oz. per ton of material.

"Crushed bones." The distillate from 100 grammes of substance yielded 0·007 grammes of dry sulphide of arsenic—equal to 0·0056 of $As_2\ O_3$—equal to 2·0 oz. per ton of bones.

Hence, assuming one ton of each of the two materials to be converted into superphosphate by means of a sufficiently arseniferous acid, the quantity of *arsenious acid* eliminated as vapour of fluoride or chloride would amount to about—

15·2 ounces in the case of the "*mineral*" (or coprolites),
and 2·0 ,, ,, the "*bones*."

Along with this you will receive a set of specimens, the labels of which have the following meanings:—

"A." Part of the arseniate of magnesia and ammonia from the "*Charleston mineral*."

"B." Arsenic mirror from the "*condensed vapours*."

"C." Mirror from part of the 7 millegrammes of $As_2\ O_3$ from the "*crushed bones*."

"D." Deposit of arsenic and arsenious acid from the "*air*" *experiment.*

I remain, Dear Sir,

Yours sincerely,

W. DITTMAR.

The next professional chemist to whom I refer holds a position that makes him a peculiarly eligible witness. Dr. E. J. Mills has for his *specialism* the teaching of intending manufacturers the principles on which the chemical manufactures depend, beyond what is usually taught in the scientific chemistry classes :—

Letter from EDMUND J. MILLS, D.Sc. (Lond.), F.R.S., "*Young*" *Professor of Technical Chemistry in the Andersonian College, Glasgow.*

Glasgow, May 17, 1876.

Dear Sir,

You have requested me to perform some experiments bearing upon the manufacture of bone manure, and more especially in relation to the question : Whether arsenic is necessarily evolved in the process of preparation ?

I. Bone manure is prepared by mixing oil of vitriol with bones (to which other animal matters may be added), and agitating thoroughly; the mass becomes much heated, and evolves abundance of fumes. After this it is cooled, dries up, and is turned over from time to time. If arsenic is given off with the vapours, we must therefore seek its origin (1) in the bones, or (2) in the vitriol, or (3) in both. Orfila's statement, made many years ago, that bones and flesh naturally contain arsenic, has been amply refuted, and indeed withdrawn by himself. The possibility of the evolution of arsenic depends, then, on its presenee in oil of vitriol.

II. *All oil of vitriol, unless very specially prepared, contains arsenic.* Oil of vitriol is made from (*a*) pyrites, and (*b*) sulphur.

(*a*) Pyrites vitriol inevitably contains arsenic, derived from the combustion of an arsenide therein present. If the manufacture of the vitriol has been conducted with proper care, and especially if only the proper proportion of nitre has been used, the arsenic is in solution as arsenious acid; but under the influence of an excess of nitrate, arsenic acid is necessarily formed. Hence arsenic acid is more likely to appear in the first of a series of chambers. Thus, in vitriol from a first chamber, my assistant has found 0·49 per cent. of arsenic (reckoned in the arsenious form), some of which was in the condition of arsenic acid; in a third chamber from the same works, the percentage was 0·07 per cent. In the former case the vitriol smelled strongly of nitrous gases. The specific gravities of the two samples were nearly the same, viz., (1) 1·54; (2) 151.

Three other samples of pyrites vitriol were examined. (C.) sp. gr. 1·44, contained 0·05 per cent. arsenic; (A.) sp. gr. 1.68, contained 0·03 per cent.; (N.) sp. gr. 1·74, contained 0·12 per cent.

According to the recent experiments of Thorn, oil of vitriol contains on the average 0·098 per cent. of arsenic.*

On the whole, then, we may expect pyrites vitriol to contain about one-tenth per cent. of arsenious oxide, if of the specific gravity ordinarily selected in making bone manure.

(*b*) Sulphur vitriol is liable to the same contamination, either because (1) the sulphur used is received from vat-waste, or (2) because of the presence of arsenic in the natural sulphur used, or (3) because of its manufacture in a chamber previously employed for making pyrites vitriol. It is not probable however, that this kind of vitriol will be found to be arseniated to the same extent as pyrites vitriol. Data on that point are wanting. I have found 0·01 per cent. of arsenic in a sulphur vitriol; but whether the smallness of this amount is due in part to the strength of the acid [it was of sp. gr. 1·81] I am

* QUERY.—What quality of pyrites is used in that part of Germany where Thorn made his observations on sulphuric acid manufacture? J. A.

unable to state. If it were proposed to use the sulphur acid for bone manure making, this point would deserve investigation.

NOTE.—It deserves to be mentioned that two of the samples of pyrites vitriol referred to above contained *antimony.*

III. If pure calcic phosphate were mixed with arseniated oil of vitriol, the evolution of arsenious oxide would not be intelligible. But when we bear in mind that bones, flesh, blood, and the like, all contain soluble chlorides, it is evident that, in contact with such vitriol, they must give off arsenious chloride. Cooked or weathered bones, of course, contain much less soluble chloride than bones in the natural state. Dried blood contains much more soluble chloride than bones. There is also present in bones, but especially in teeth, a very recognisable quantity of fluoride, which, so far as it may be able to dissolve in the sulphuric acid, must evolve the volatile arsenious fluoride.

The sample of bones you handed me* was of unknown origin, and contained 0·09 per cent. of soluble chlorine (as chloride). 390 grammes of this were heated with 135 cubic centimetres of the pyrites vitriol (N.) above referred to; the temperature was kept at 100°C. for an hour, and at 110°C. for half-an-hour. The products were drawn, by means of an aspirating arrangement, through water, aqueous potash, and aqueous nitrate of silver successively. The action was very vigorous. A very large quantity of water was given off, containing arsenious chloride corresponding to 0·004 grammes of arsenious oxide: hydric fluoride was not detected. The water held in suspension a large quantity of solid fatty acids, which had an odour of fatty hydrides. A large amount of sulphurous acid was likewise evolved, and some body of apparently aldehydic nature.

The residue in the flask was next heated for ten hours to 130°, under the same conditions as before. All the phenomena previously observed were now repeated, except that of arsenious chloride. A quantity corresponding to only ·002 gramme oxide was found.

I am informed that bones often contain more soluble chloride than the sample with which I worked. By using richer bones, I should expect to get off more arsenic from the vitriol I employed. It is important to notice that most of the arsenic in the above experiments came off at a temperature near to the boiling point of water. This temperature must often be exceeded in a manure work.

IV. The vapour evolved in the mixing chamber, when carried off in a flue, deposits a quantity of dust, some of which you handed me labelled "condensed gases." The sample contained about 0·11 per cent. of arsenious oxide.† It also contained aluminic silicate; and enough fluoride to etch glass very freely.

I am, Dear Sir,

Yours very truly,

Dr. Adams. EDMUND G. MILLS.

Having observed in chemical periodic literature that Dr. Milne of this city had given special attention to the Chemistry of Manures, I applied to him, and he very cordially embarked in an enquiry that lay so near his customary avocations. He agreed to make a thoroughly practical investigation; and, if warranted by the results,

* I subsequently learned that this sample of bones had been "weathered" to an exceptional condition.

† This is equal to about 2¼ lbs. of arsenious acid to a ton of the moist material, nearly three-fourths of which consists of water. This sample is a portion of the same deposit examined by Mr. "M." [see page 53], and it will be noticed that the results obtained by both gentlemen are almost identical. J. A.

to illustrate each stage of the problem by one or more carefully conducted experiments. I had daily opportunities during five weeks of observing the conscientious precision with which every detail indicated in the following Report was made a matter of personal handwork:—

Report by Dr. JAMES M. MILNE, *Analytical and Consulting Chemist, Public Analyst for Dunfermline, Govan Parish, Kinning Park Burgh, &c.*

144 West Regent Street,
Glasgow, 28th June, 1876.

At the request of Dr. Adams I have made a number of experiments, for the purpose of ascertaining whether or not arsenical vapours are given off during the manufacture of artificial manures. A careful consideration of all the facts laid before me as to what had already been done in connection with the subject, led me to decide on making a series of experiments which should, if possible, trace the contamination through its various stages. The following is a brief account of these investigations:—

I. As regards the so-called "Chamber Acid" employed in such manufactures, the fact that the acid is made from "Pyrites," a mineral always containing a proportion of arsenic, is a sufficient reason for anticipating the presence of a certain amount of that element in the acid so produced. In a sample of chamber acid (which I shall call A) procured from a work in Glasgow, a careful determination gave ·14 per cent. of arsenious acid, or upwards of 3 lbs. per ton. Another sample (B), obtained direct from the chamber a short time ago, gave no less than ·44 per cent. of arsenious acid, or nearly 10 lbs. per ton.

II. The presence of this amount of arsenic in the last sample induced me to make enquiries as to the source of the pyrites from which it had been made, and, having procured a specimen, I proceeded to ascertain the amount of arsenic in the ore. The determination was repeated three times, with concordant results, and gave as the mean ·62 per cent. of metallic arsenic. In practice it is usually reckoned that fully 70 per cent., or nearly three-fourths of the arsenic present, is volatilised along with the sulphur. An examination of the above figures shows that the relation between the arsenic found in the acid and that found in the pyrites from which it was produced agrees closely with this theory.

III. A mixture of 165 parts bones, 85 parts coprolites, and 125 parts chamber acid (A), to which a quantity of arsenious acid sufficient to bring the total amount of arsenious acid up to ·5 per cent., were placed in a large retort. The acid was added by means of a stoppered funnel. A tubulated receiver was fitted air-tight to the retort, and connected with two Woulf's bottles, a current of air being drawn through the whole apparatus by means of the aspirator. A regulated gentle heat was applied to the retort for several days. Distinct evidence of the presence of arsenic was found in the distillate. *This experiment was repeated three times.*

IV. The next experiment was designed to imitate an average process of bone manufacture, and had for its object, 1st, an approximate estimation—not an absolute determination—of the amount of arsenic given off; and, 2nd, an approximate estimation of the total amount of vapours of all kinds given off from the manufacture within a limited period. At Dr. Adams' suggestion, I shall avoid technicality in its description.

660 parts of bones, 340 parts of coprolites, and 900 parts of chamber acid (B), weighing altogether 4 lbs. 3 ozs. avoirdupois, were placed in a large glass retort, the neck of which was adjusted *very loosely* in a wide-mouthed bottle of about 1½ gallon capacity. The vapours arising from the mixture passed freely over into the receiving bottle, which was kept cool by a cloth frequently wetted.

A gentle heat was applied to the retort, and kept up for 42 hours. At the end of this time there remained in the retort (the top and neck of which were strongly corroded) 3 lbs. 6 ozs. of manure, and in the receiving bottle about 10 ozs. of a dense and very offensively-smelling liquid. The deficiency of 3 ozs. from the original weight of the materials is accounted for by the fact that as much had escaped between the neck of the retort and the wide mouth of the receiving bottle, and had become dissipated in the surrounding atmosphere.

The manure was in the moist condition it usually presents when removed from the mixing-pit and before it has undergone the drying and sifting operations which fit it for sale.

From the 10 ozs. of liquid which had condensed and collected within the receiving bottle I extracted as much white arsenic (arsenious acid) as gave a proportion of 2 ozs. 160 grs. for every ton of manure. There is no doubt, however, that this amount of arsenic is under the mark, because a considerable quantity must have passed along with that more volatile portion of the vapours which were not collected and condensed, but had escaped freely into the atmosphere through the open mouth of the receiving bottle. This free communication of the interior of the large receiving bottle with the outer air was purposely arranged so that the results of the experiment might not be cavilled at as being due to exceptional manipulation. The arsenic actually collected is to be regarded, therefore, as an absolute proof, not of all that *can* be volatilised, but that *at least* this quantity *had* been volatilised, and would have passed off into the outer air if it had not been intercepted and collected within the atmosphere of the large receiving bottle.

V. The possible production of arseniuretted hydrogen, by the action of arsenical acid on the iron mixing-boxes and screw agitators used in the manufacture of manures, was not lost sight of; and in order to test this point the following trial was made:—

About 15 parts bones and 2 parts iron turnings were placed in a small retort having a very short neck, to which was attached a bulb containing solution of sodium hydrate, and next a Geissler potash bulb containing solution of silver nitrate. Some of the arsenical acid (B) was poured upon the mixture in the retort, and a gentle heat applied, a current of air being drawn through by the aspirator. After some time the characteristic black rings began to appear on the tubes in the silver solution, and then a black deposit, which gradually increased to a copious amount. The solution was filtered off from the deposit, and cautiously tested with ammonia, when the yellow arsenite of silver was distinctly rendered visible. Another portion of the solution was placed in a Marsh's apparatus, and spots of arsenic obtained on porcelain. This clearly demonstrated the fact that arseniuretted hydrogen had been evolved. In the sodium hydrate contained in the bulb next the retort, arsenic was also detected by Reinsch's process. In neither of these solutions was any attempt made to determine the amount of arsenic present, as apart from the difficulty of determining such small quantities, the main point was to prove the fact of its evolution in that form of combination.

This experiment was repeated, using equal parts of the arsenical acid (B) and water, to imitate the dilute condition to which the acid attains during the manufacturing process. The quantity of arsenic given off in the form of arseniuretted hydrogen was very considerably greater than when the acid was used in its full strength. It is therefore evident, that as the acid becomes dilute—which it actually does during its action on the bones—there is a greater development of arseniuretted hydrogen.

VI. A quantity of the manure produced in the foregoing experiments was placed in a large wide-mouthed bottle, which was then closed tightly with a cork having two holes pierced in it. Through one of these a moderately wide glass tube passed almost to the bottom of the bottle. In the other was inserted a tube containing cotton wool. This tube was connected with two bottles containing sodium hydrate, and arranged, so that on connecting the last bottle with the aspirator a current of air was drawn through the wide tube, and after passing over the manure, made its exit through the soda solution. The large bottle was placed on its side and the contents occasionally shaken up. The air stream was kept up night and day for a month. The soda was then neutralised with pure sulphuric acid, and placed in Marsh's apparatus, when arsenic spots were obtained on porcelain.

We thus find that arsenical fumes continue to be given off by manures after being manufactured, and when lying stored up for transit. It is easily to be understood that the action set up in the mixing box and receiving pit will go on more slowly, but not less surely, for a long time after the manufacture.

VII. I have also examined a sample of "Condensed Vapours," handed to me by Dr. Adams, from which I obtained arsenic in notable quantity by well-known processes.

VIII. From these experiments it is evident that the presence of arsenic can be clearly traced from its source in the pyrites into the sulphuric acid; from thence into the vapours and gases evolved during the action of the acid on bones and coprolites in the manufacture of manures; and finally, into the atmosphere which has been in contact with, and which proceeds from, the manufactured article.

JAMES MITCHELL MILNE.

PART III.

GENERAL OBSERVATIONS.

Dr. Milne is the seventh professional chemist whose direct and positive evidence I have now placed on record. The roll of names will be extended without a break by every professional chemist who really, and with earnest purpose, enters upon the enquiry.

The results obtained by Professors Dittmar and Mills, and Dr. Milne, require little comment. In common with the chemists who preceded them in the enquiry, they were aware of the habitual contamination with arsenic of the sulphuric acid made from pyrites. They were aware that this acid is in general use by manufacturers, particularly in the making of manure. They had no difficulty in proving that the arsenic is volatilised, and passes off in the vapours of manure. And they had no difficulty in finding arsenic in the deposit of condensed vapours collected in a manure work. In Professor Mills' experiment with bones so "weathered" or decayed as to contain only a twentieth part of their normal amount of chlorine, it is surprising that any arsenic was given off. And yet the superphosphate made from these bones, on being subjected to continued heat, resembling that of manure heaps while in store, continued to give off arsenical vapours while the experiment lasted. The bones used by Professor Dittmar were of better, although still of poor quality, and the arsenic which was evolved *exceeded* 2 oz. per ton of manure. With coprolites, the arsenic evolved *exceeded* 15 oz. per ton. Dr. Milne's superphosphate represented the staple article, viz., bones conjoined with coprolites, and the arsenic given off in vapours during the first stage of manufacture *exceeded* 2 ozs. 160 grains per ton of manure. None of the experiments shew the exact quantities of arsenic which *can* be given off. They shew only an approximate estimate of the quantity given off during the restricted time that the materials were under observation. It was considered sufficient to shew that *arsenic was unfailingly given off;* and that it was given off *in considerable quantity.* All the experiments shew that *arsenic continued to be given off however long the experiment lasted.* The arsenic is disengaged rapidly at first, and more slowly afterwards, as illustrated in that experiment of Dr. Mills, which was divided into two stages, and where more than double the quantity of arsenic was given off in the first, than in the more prolonged second stage. Attention is drawn by Dr. Mills to the fact that a high temperature is not *necessary* to ensure the disengagement of arsenical vapours. This I surmised, and therefore suggested an "air" experiment. In Professor Dittmar's "air" experiment, the superphosphate already dried by a fanning machine in the factory, and brought to the condition of a loose crumbling powder, was exposed in his laboratory to a cool current of air ranging from 30° to 50° F., and it continued to give off arsenical vapours for as many days as it continued under observation. In Dr. Milne's "air" experiment, the sample of superphosphate carefully prepared in his own laboratory, was subjected, a week after its manufacture, to the same process as that adopted by Professor Dittmar, and kept under observation for a month, during which it continued to impart to the atmosphere arsenical contamination. No better illustrations than these "air" experiments could be adduced of what is occuring where there are stores of manure. The ingenious experiments of Mr. "M.," shew that the so deservedly dreaded arseniuretted hydrogen is disengaged in the presence of iron under conditions that commonly occur in the processes of actual manufacture; and Dr. Milne's corroborative experiments shew that the evolution of this insidiously deadly gas is not materially hindered even although the acid employed is of considerable strength, and in such excess, as regards quantity, that the strength is little reduced by the dilution which takes place under the chemical action.

The certainty, the facility, and the persistence with which arsenic is disengaged under all the varied conditions of every experiment, are striking commentaries on Dr. Macadam's very emphatic assertion, that "any arsenic which goes into the manure, stays in the manure."

Let no one suppose that the quantities of arsenic so given off are of trifling import. "We frequently encounter," said Prof. Dittmar, "vapours in the laboratory which are bad enough, and do not mind "them very much, but I certainly should not like to breath an "atmosphere so contaminated." And the other professional men, chemists and physicians, who have shared in this enquiry, also share in this opinion.

It is true that these are mere laboratory experiments of ounces and grains, but they leave in no manner of doubt what is occurring where hundreds and thousands of tons are in question. From such data we may estimate the character of an atmosphere that is liable to be, and that frequently is, contaminated with the quantities of arsenic specified. A single ounce of arsenic weighs 437½ grains, and according to our standard authorities, from 2 to 3 grains of arsenic is a fatally poisonous dose for an adult. In the liquid state, and still more in the gaseous form, the potency of the poison is greatly increased, and in the latter condition it is also more subtile and more delayed in its action, unless the dose be very large. Now, according to my observation, and the state of my information, there are pounds weight of arsenic being daily disengaged in vapours from many manure works.

Thus, at the small works of Bunchrew, there was used at each "mixing" about 25 tons of raw material, producing about 20 tons of manure. It is shewn by the experiments of Professor Dittmar and of Dr. Milne, that in the manufacture of these 20 tons of manure there passes, or are liable to pass, into the atmosphere *certainly not less* than 3 lbs. of white arsenic (arsenious acid). If made from coprolites instead of bones, the quantity of arsenious acid volatilised will be about 19 lbs., or if from a proportion of bones and of coprolites that is frequently employed, the quantity of arsenic volatilised will be about 12 lbs. How much of this arsenic comes away in the first rapid rush of the vapours, or how much in the slow and continuous after-exhalations—how much on an average per hour, or day, or week—I do not at present care to enquire. At this stage of my argument, averages of figures would only mislead, if they were so applied. I am anxious not to over-strain my evidence, and prefer that any earnest enquirer should draw his own inferences from the facts I am bringing forward, being well satisfied that plain truths appeal to the judgment with greater simplicity and likelier acceptance than forced inferences. Where two forces are represented—one by 2 per cent. and the other by 98 per cent.—it would be mere folly to say that the "average" force was 50 per cent. *The forces present in arsenical contamination of atmosphere, caused by manure works, are of a maximum and of a minimum intensity,* and each may have a mode of action which has yet to be investigated and determined. One parcel of bones used for manure contains 2 per cent. of chlorine, and another only a twentieth part of that normal amount. One sample of sulphuric acid yields 1 lb. of arsenic to the ton, and another yields 13½ lbs. When these elements of danger are brought into action, the minimum amount of atmospheric pollution cannot under any circumstances be less than unwholesome, and the maximum amounts in certain circumstances may be positively dangerous. I have already pointed out that the injury which may result from exposure to animal miasms or chemical gases, depends much on the amount of the dose, and degree of concentration on the one hand; and on the other upon the natural vigour or acquired habit of the individual to resist it. A middle aged robust man, of lively vitality and moderate sensibilities—in short, an average healthy man—may sustain, with only a sense of passing discomfort, a concentrated dose of the worst that a manure work can inflict. Another man, who is not an average robust man, but who may be upwards of 70 years of age, who may be delicately nurtured and upheld, who may have refined sensibilities and a strong belief in the potency of offensive animal exhalations, may succumb immediately to the shock of the impression which has revolted all his senses. The blow that will not stagger a man, prostrates a child.

In estimating the injurious potency of vapours from artificial manures, I therefore take into account three forces or sets of conditions: *First*—The emanations from decomposing animal matter, which in their simplest form and of known composition, are—to an individual not accustomed—never less than offensive and unwholesome; and, when accumulated, are oftentimes dangerous. *Second*—The "organic poison" or "animal miasm" of unknown composition, which may be contained in, or developed from the exhalations. *Third*—The positively poisonous arsenical contamination, which—as a separately injurious force—is grafted upon, and superadded to the other hurtful agencies.

And here I must take a short digression, with the object of shewing that, while holding up prominently, that which is probably the most important constituent of the vapours of bone manure, I am not unmindful of other efficient elements of mischief that are present, and to some of which I have already alluded. At page 12 I refer to the large volumes of dense watery vapours and volatile acids that are disengaged under the chemical action of sulphuric acid upon bones. These volatile gases, acids, and other products of animal matter thus decomposed consist chiefly of carbonic acid, sulphuric acids, nitrogen acids, hydrochloric acid, and fluorides, associated in several cases with water. The total amount disengaged is so considerable as to form nearly one-fifth part in weight of the whole material employed. Some individuals have been startled and even sceptical when told that about four hundredweights out of every ton of the material disappears from the factory in the shape of vapour. But there, nevertheless, are the facts, as brought out clearly in Dr. Milne's experiment, and easily capable of being verified by the manufacturer, if so minded. I have not, however, met with an employer or workman who looked at the matter in this light, much less endeavoured to determine it. Any one will be aided to a recognition of this important point when it is borne in mind that about one-half of the substance employed consists of a fluid, and that the entire mixture becomes heated above the boiling point of water, and remains for a long period in a state of warmth far exceeding that of the surrounding temperature. There is necessarily given off from such a variously compounded and half-boiling mixture a large quantity of moist and dry vapours. Any person of ordinary information, although not a chemist, may understand as much. These vapours are all more or less offensive in smell, irritating, and irrespirable, and, setting aside the organic exhalations, and restricting consideration to constituents the composition and properties of which are known, there are some that are injurious and positively dangerous. Let me mention two of the constituents, viz., Fluorine and Antimony.

Among laboratory accidents there is scarcely another so dreaded by the chemist as that arising from fluorine; or, as I should rather say, its hydrogen compound, Hydrofluoric acid. Dropped upon the skin it occasions deep, painful, and malignant ulcers, caused by the powerful corrosive action exemplified in its property of corroding glass. In vapour, its white suffocating fumes exercise a peculiarly hurtful effect on the eyes, throat, and air passages, far exceeding in intensity the comparatively transient irritation produced by hydrochloric acid. At the sametime, it is only when in a concentrated form that it is likely to occasion injury that can be directly traced. To this agent I owe, no doubt, a sore state of the eyelids, and a painfully irritable and, at times, spasmodic affection of the windpipe, not yet recovered from; and which has caused on several occasions a distressing sense of immediately impending suffocation. It originated on the occasion of my second visit to Bunchrew works, when I made an imprudent attempt to penetrate the "mixing pit" during a momentary interval in which the entrance was unbarred to permit myself and colleagues to witness the intense chemical action going on. I had it in view to fix a thermometer where I could test the degree of heat evolved, and being very intent on my object, and seeing what seemed a good opportunity, I forgot the danger. But, although I held my breath, sufficiently as I thought, and persisted, and made a second attempt, I could not persevere, for even the few seconds necessary. My fellow-witnesses acted with greater discretion, and a very distant "whiff" made an impression upon them so lively that they retreated and took my word for the rest. Mr. Archer, sanitary inspector for Leith, deponed in court, in connection with the present inquiry, that he had so suffered from a similar imprudent attempt that he had made to enter a mixing chamber during the process of dissolving, that he was for sometime ill and laid up for treatment in the hospital. Hydrofluoric acid, either alone or associated with arsenic, or with antimony, is therefore an agent to be greatly feared and avoided.

Antimony is a metallic irritant poison, only less potent than arsenic, to which it has a strong resemblance in its chemical re-actions, symptoms, and hurtful results. It is frequently—almost invariably—present in iron pyrites. I have reliable information that the Spanish pyrites, of which so much is used, contains an average proportion of antimony, amounting to 0·15 °/$_{o}$, which is equal to one ton of antimony in 666 tons of pyrites. Antimony, like arsenic, is volatilised by heat, and passes into the vitriol chambers; and like arsenic, it is disengaged from the sulphuric acid during the manufacture of manure; for, like arsenic, it combines with chlorine, and is volatilised as a chloride. My chemist friends found it in the pyrites, in the sulphuric acid, and in the "condensed gases." Antimony, when respired in the state of vapour, produces the same effects as when taken into the stomach, viz. :—Pain of stomach, vomiting, and great faintness, with depressed action of the heart. A. Fourcroy* speaks of 50 persons, among whom all the symptoms of poisoning, short of fatal results, shewed themselves within ten or twelve hours after having breathed antimonial vapours. M. Lohmier †

* Orfila, Traite de Toxicologie, 1852, vol. 1, p. 650.
† Gazette Medicale de Paris, Sept., 1840.

describes the symptoms of poisoning present in the cases of four individuals who were exposed to the vapours of antimony in an establishment where they were disengaged in the form of antimonious and antimonic acid, and chloride of antimony. M. L. was guided to the cause by being unable to trace the symptoms to any known disease. But I will not extend this digression, and I only refer to some "cases" to suit the requirements and capacity of a class of individuals who do not think for themselves—who only "follow their bell wethers"—and who must have a precedent, "a case in point," before recognising a source of danger that has not been proved to have been actually destructive.

I cannot but regret that in the great majority of manure works there are no really effective preventive measures against these injurious pollutions of the atmosphere. The subject is ignorantly trifled with as a mere matter of more or less disagreeable "smells." And from my personal experience, there is forced upon me the conviction that no general or efficient preventive measures will be practised, unless under legal compulsion. To shew the grounds of this belief, I cite two illustrations which I suspect are common enough.

One manufacturer has a smattering of chemical knowledge, such as a boy will acquire in a three months' laboratory course, but is otherwise quite ignorant of the principles of sanitary science, and owing to the jealous exclusiveness of rival manufacturers, or to his having little desire for information that does not seem to be practically profitable, he has little knowledge of the varied appliances which may be elsewhere in operation. For the construction and conduct of his works he leans, it may be on a so-called "experienced foreman," who is callously insusceptible to the mere matter of smells, and as stolidly opinionative in his "experience" as his master is self-deluding and self-sufficient in his scientific knowledge. How is the factory of such a man to be improved, or how hindered from becoming a dangerous nuisance? Another manufacturer makes no pretence to experience or to science. He betakes himself to what seems to him very simple processes of manufacture, and carries them on by some rule of thumb gauge, gathering experience as he goes. He uses honestly the best material in the market, is unconscious of causing danger, or of giving offence to his neighbour, whose complaint he regards as overstrained sensibility, although he cheerfully spares neither trouble nor expense to avoid either danger or offence to that neighbour, if he only knows how. He is simply ignorant of the conditions and of the forces which he has brought into action, and therefore does not know how to control them. In both cases here illustrated there is needed the repressive arm of the law, but in the latter case it is difficult to withhold sympathy when legal penalties are incurred. In the special case of the Bunchrew Works, I was impressed with a conviction, which I stated in court, that the proprietor was conscientiously desirous to do his very best, and had already done so to the utmost of his knowledge—he had sought advice, and, unfortunately, had been insufficiently advised.

With regard to actual injury, which may be produced by poisonous vapours—whether chemical gases or organic miasms—disengaged in the manufacture of artificial manures, I wish it to be distinctly understood that I am not at present undertaking to prove cases of illness and cases of death. My object is not to shew that poison has already done its work, but that death is in the cup—not to chronicle shipwrecks, but to map out currents, shoals, and hidden rocks. I am endeavouring to demonstrate that there is an occupation wherein neither the workmen employed nor the people who live within the reach of his operations have been hitherto made aware that they are liable to breathe, and actually do breathe, an atmosphere contaminated with the admittedly deadly poison of arsenic; and this in addition to the risks of an atmosphere already made impure, offensive, and unwholesome from other contaminations. I may be told that the breathing of arsenical vapours to the extent shewn by me does no harm to the animal economy, and I may be referred to an alleged healthy condition of workers in bone manure, and to an alleged absence of casualties in connection with their employment, but I will not at present go over that ground. I will assume that there is a sufficient capital of common sense in the medical and general public as will reject the notion that breathing arsenical vapours makes a man healthy and keeps him robust. Future enquirers can examine, as should be examined, the statistics of morbility and of mortality in what is quite a new trade—an industry of the present generation. As yet, there has been no special enquiry to trace the after progress of workers whose names disappear from the pay-roll of these establishments. But I will offer some considerations just as they readily present themselves, and which future enquirers may profitably bear in mind.

The educated man who consciously collects data, compares them, and deliberately draws conclusions, need never be at a loss for an explanation of individual cases of immunity from influences that are generally hurtful, and therefore the well-informed physician can draw from his own or from recorded experience illustrations, individual as well as aggregate, of the effects of *habit* and of *idiosyncracy* in rendering the body not liable to poisonous agencies—can adduce parallel instances from which an analogy can be drawn that will meet all that can be advanced with regard to manure vapours. Familiar examples are seen in common feats of dexterity and of endurance. Blondin walks in mid air upon a stretched cord—Leotard darts like a bird from his swinging trapeze—Webb swims across the British channel—and Weston walks for days and for nights continuously. These are examples of trained acrobats and athletes, and such individuals are not uncommon—can in fact be collected and assembled in groups. And from the combined action of these two well-attested principles, which permits the existence of such individuals, and the formation of such assemblages, viz., the influence of habit and idiosyncracy, there often results the formation of groups of workers in unwholesome occupations, from among whom all susceptible constitutions are in a great measure eliminated. I refer to the labours and writings of Ramazzini, Patissier, Parent Duchatelet, and Thachrah, for abundance of such illustrations, as well individual as in the mass. "Use doth breed a habit in a man," as is seen in the matter of mere relish for particular articles of food, which in one individual revolts, and in another attracts appetite. Hence the adage that "what is one man's meat is another man's poison." The retired East Indian masticates with keen enjoyment the hot capsicum pickle that sets his neighbour's throat a-fire and brings tears to his eyes. A "three-bottle club" has been known, every individual member of which could finish his three bottles of port at a sitting, and finish off with something stronger. But the present generation has no knowledge of associations or groups of drinkers, where the capacity to imbibe three bottles of port and one of brandy was a necessary qualification for membership, and is therefore little likely to sympathise with the regrets expressed by a gentleman of the olden time for the premature demise of a promising young aspirant for club membership, who had "died in the training." With regard to medicines, while a half ounce of laudanum will certainly kill in ordinary circumstances, there are instances common enough where an ounce or more is taken at a draught, and the practice continued daily with impunity, under the influence of gradually-increased doses. I might cite many other drugs. But a more apposite illustration of the modifying influences of idiosyncracy and of habit is to be found in the existence of individuals who are in the regular custom of eating arsenic throughout long periods of time, and with alleged or seeming impunity.

That there are "arsenic eaters" as well as "opium eaters" or "three-bottle men" is now a thoroughly established fact. Dr. Maclagan* gives a succinct sketch of the existing information on this subject at the time when he, accompanied by Dr. J. Rutter, visited Styria in 1864, and personally ascertained that there are individuals in that country who habitually take arsenic in doses, any one of which would be certainly fatal to persons not accustomed. One young man, in the doctor's presence, eat five grains of arsenious acid, powdered and placed on a piece of bread. This person had been in the habit of taking a similar dose twice a-week for a year and a-half previous. Another man, at the same time, swallowed about six grains of arsenious acid, and stated that he was in the habit of taking a similar dose about once a-week, that he had done so for years, and that he knew individuals who habitually took it in still larger quantities. Dr. Maclagan, in addition to his personal observations, obtained introductions to several medical men of the country, official and others, and in a variety of ways obtained such conclusive

* Edin. Med. Journal, Sept., 1864, p. 200.

confirmations of the accuracy of the evidence given by Dr. Von Tchudi, the late Professor Johnston of Durham, Dr. Schafer, Dr. Roscoe of Manchester, Dr. Knappe, &c., &c., that there is no longer doubt on the question. At a recent meeting of the German Association of Naturalists and Physicians at Gratz (viz., September, 1875), Dr. Knappe read a communication on the "Arsenic Eaters of Styria,"* embracing interesting details of numerous cases. He states that there are many arsenic eaters in Styria, who begin the practice early and continue it to an advanced age. It is considered among the people to be a disreputable practice, and therefore one to be concealed as much as possible, just like opium eating in this country; and owing to the strict laws regarding the sale of poisons, they cannot get the arsenic by open purchase. For these reasons, accurate statistics shewing the wide prevalence of the habit cannot be got. Dr. Knappe persuaded one of these arsenic eaters to come and live with him for a few days, and he was enabled to test the ingestion of the drug and its elimination in the secretions from the body. He exhibited two individuals at the above meeting (and from what he states he might have brought forward a group of arsenic eaters), one of whom took $4\frac{1}{2}$ grains of yellow sulphide of arsenic, and the other 6 grains of arsenious acid, in the presence of the meeting. Dr. Knappe speaks of doses of 17 grains, but states that "the greatest quantity I have *seen* taken is 14 grains." Dr. Schafer's cases, published in vol. 41 of the Reports of the Imperial Academy of Sciences of Vienna, embrace one where the individual took 30 grains of arsenious acid every second day. But while such wonderful exceptional instances prove the *rule* for which I am contending, the experience of medical men in other countries shews that the habit can be acquired only with difficulty and through danger; and that the effects of the imbibition of arsenic, however carefully practised, are, when carefully traced, found to be usually deleterious, and ultimately fatal, through the induction of chronic abdominal affections. Dr. Parker† of Halifax, Nova Scotia, narrates such a case, which came under the professional charge of Dr. Tupper and himself. A photographic artist who applied to him for relief from what he considered dyspeptic symptoms, viz., pain after meals, bad rest at night, and frequent vomiting, aided the doctor's diagnosis by asking if arsenic could account for his condition; and then stated that he had for four years taken arsenic daily, being induced to do so by an article in a newspaper. He began with small doses on the point of a penknife, and for five months preceding his application to Dr. Parker his daily dose had been two and three grains. The last dose he had taken about sixty hours before calling in medical aid, and about five days before he died. Slight traces of the poison were obtained in the viscera. This individual "died in the training." And it is the extremely great probability of *somebody* dying in the training that should be

* Translated and abridged in London Medical Record, Nov., 1865, p. 612.
† Edin. Med. Journal, 1864, p. 116.

present to the mind of an enquirer into the effects of noxious vapours from manure factories. It is the extraordinary influence of habit in modifying the normal susceptibilities of workmen engaged in offensive employments, but which may not modify those of innocent and non-interested outsiders exposed to their operations, that should not be forgotten when any interested manufacturer attempts to measure from the immunity of *trained* or *unsusceptible* individuals the susceptibilities of individuals who have not been "trained."

Dr. Taylor, in his standard book of reference on poisons, directs special attention to the fact that a person "who recovers from the first effects of arsenic, may still die from exhaustion or other secondary causes many days or weeks after," and he cites several well marked instances. I regard Dr. Parker's case an illustration of the kind. The peculiarity increases the difficulty, at all times considerable, of distinguishing the symptoms of poisoning from those of disease, particularly when only minute doses have been imbibed from time to time, as when individuals, through their occupation or residual proximity, are daily exposed to a contaminated atmosphere. In this way the effects of poisoning may be mistaken for disease, more especially as in slow poisoning from the irritant poisons, their course often is gradually to cause irreparable injury to the digestive and lymphatic system, and finally to destroy life.* A considerable interval often occurs between the reception of arsenical poison and the full development of the symptoms; and where the imbibition of the poison is unsuspected, the effect may never be traced to the cause. In most of the cases of poisoning by arsenical vapours to which I have already referred, the symptoms came on speedily after reception of the poison. Moreover, the individuals were persons of education and intelligence, and by communicating their own well-informed observations, the characteristic symptoms were more readily traced and satisfactorily authenticated. But in the cases of individuals employed at factories where arsenical fumes are disengaged, or who are otherwise unwittingly exposed to such vapours, the conditions are altogether different. The place that is for even a few hours left vacant by a labourer in an occupation that requires no skill or training is easily filled up. One man suddenly sickens, and is ill for a few days; another has a protracted illness and is laid aside for weeks; and new hands occupy their posts with little or no comment. The result may never be learned, and if enquiry is made, then, in the absence of all suspicion of an occult cause, it is assumed that the individual has been drinking, or has caught cold, or has had a bilious fever, or British cholera, or dysentery, or some such ready or seemingly likely explanation is offered. If unhealthy employment is suggested, then it happens that familiarity with what at the worst is only regarded as a rather bad "smell," a rather disagreeable but necessary accompaniment of his occupation, makes the sufferer and his friends either contemptuously indifferent or despairingly resigned.

* Beck's Medical Jurisprudence, 7th edit., 1842, p. 760.

It is not strange that they are as little able to connect the date or circumstances of the first access of illness as are other individuals to connect the date of the circumstances under which they contracted typhoid fever or cholera. Just as difficult is it to demonstrate the cause which directly produces the gradually diminishing vitality and the dyspeptic phenomena which befal the susceptible individual who lives in a neighbourhood where, perforce, he breathes an atmosphere frequently charged with dilute poisonous vapours. Just as difficult is it to tell the exact day, week, or month in which the Sheffield knife-grinder has inhaled the culminating quantum of steel particles which fatally injured the structure of his lungs, and reduced his expectation of life to one-half the promised scriptural age. And just as difficult is it to tell the duration of residence in a warm climate or a marshy district that gives a man diseased liver or ague. But it is the province of sanitary science to forecast de-vitalising influences which ignorance or apathy disregard, or, if noted, regard as unavoidable concomitants of our social relations. I am able now to draw, from a long special experience (and, as I believe, a habit of observation that is ready to recognise or to infer one truth as readily as another), recollections of cases of mysterious illness, or of actual death, occurring to individuals exposed to the vapours of manure factories, where the illness was to me quite inexplicable on the grounds alleged.* In some instances I have had strong impressions, which would have involved myself and others in much hazard to have actively mooted, but where, nevertheless, I have made cautious enquiry regarding cases where effect and cause could not be mathematically demonstrated, but where, as in Mr. Fraser's case, I saw no reason to doubt the truth of my convictions as to the way in which the illness had originated.

The case of Mr. Fraser is instructive, and will always be of memorable interest. Although conditions were combined in a manner that scarcely admitted of doubt, there was, nevertheless, a certain difference of opinion expressed regarding the cause of his death. The influence of the manure works could not be altogether ignored on the part of the defender, although there was a natural unwillingness

* Observant practitioners, under favourable opportunities, have met with similar cases of inexplicable ailments occurring to manure workers. On the occasion of reading the introductory portion of the present memoir to the Medico-Chirurgical Society, there was narrated by Professor G. H. B. Macleod such an instance that officially came under his observation. A woman employed in Townsend's manure work, on removing the cover of an apparatus, encountered concentrated exhalations. Symptoms such as characterise irritant poisoning occurred, and she died within a few days. She was of sound body, and there was no evidence of disease recognised. I have information of several similar instances, in one of which four individuals were exposed at the same time, suffered the same symptoms, and died within three or four days. The incident occasioned a casual newspaper notice, soon neutralised by a quickly-following paragraph to the effect that, on enquiry, there was evidence of drinking habits in one or more of the cases, and that British cholera probably accounted satisfactorily for all!

to admit the painful responsibility of the imputed result. To plead extenuating conditions was justifiable enough, but defender's counsel went much farther, and, with that boundless licence which is, with too frequent impunity, occasionally assumed by a counsel, said that the opinion expressed by Mr. Fraser's medical attendants as to the cause of death was "a gross misapplication of scientific skill." In the absence of any conceivable cause other than that alleged, and in the absence of one tittle of support from evidence, he ventured the wild hypothesis of "mental excitement" and "effects of imagination." I am in doubt if I do well to give this theory serious notice, for I observed that its author was only amusedly tolerated when indulging in the proverbial legal privilege of "abusing plaintiff and witnesses where there is no case." There seemed among his auditory such open manifestations of merriment, excited by his repeated discomfitures, ignorant questions, and absurd propositions—such a summary "putting of him to rights" when he made his little perversions of matters of fact—that I may be wrong in giving prominence to a speculation that was so promptly scouted by the common sense and fine taste of the Court. Still, there are ignorant and unreflecting, and therefore credulous, individuals, who do not look at facts for themselves, and who are impressed by propositions which might deservedly be passed by without challenge by reason of their absurdity, if only asserted with audacity—if only reiterated as if the speaker himself believed his own utterances. I will therefore say a few words on this imputed effect of imagination.

There is no question whatever regarding the essential facts of the case. They have been already referred to, but will bear recapitulation. Mr. Fraser was accompanied by his daughter at the time he encountered the noxious effluvia. She felt them severely, more severely upon this than upon any previous occasion, and she was compelled to cover her mouth with her "cloud," so that it served the office of a respirator; but her father had no protection. Young and vigorous, she did not suffer; but she observed that her father did, and that he complained that "the smell was horrible to-day," and that he was visibly much affected. The station-master, to whom Mr. Fraser explained that the smell had turned his stomach, noticed that he was looking pale and unwell, and with kindly attention placed him in an empty compartment of a railway carriage. Mr. Fraser then became very ill, hung his head over the carriage window, and continued vomiting or retching until he reached Inverness, 3½ miles distant, where he was conveyed across the platform into the Station Hotel, and medical aid was at once sent for. Dr. Mackay, who resides near the station, saw him within a very short time, and he was then lying face downwards across the bed, complaining of severe pains of stomach, and making efforts to vomit. The prostration of his strength had already become very marked. Dr. Wilson, who had known Mr. Fraser intimately for upwards of twenty years as the family medical adviser, and had never known or heard of him being ill, was soon after in attendance. And the sufferer was under the conjoint treatment and intelligent observation of these skilled and competent witnesses during the four days over which his illness extended. The active symptoms of pain and irritability of stomach, with vomiting efforts, continued for two days, and subsided on the third, excepting the pain of stomach, which still continued, leaving the patient in a state of exhaustion so extreme that, on the fourth day, when attempting to get up, he passed away in a fatal swoon. There is here no statement the result of afterthought, and no gaps in the link connecting the immediate access of illness, with its immediately imputed cause. And there is here no lack of competent observers to note and record the close-following order and character of the symptoms throughout. Neither was there any want of the fullest information regarding Mr. Fraser's conditions of previous health, habits, food, occupation of time, &c., for days previous to the morning when he left his home in his accustomed vigorous and perfect state of health.

After Mr. Fraser's death, his medical attendants declined to grant a registration certificate in the usual form, specifying that death was the result of such and such a disease. They could detect no disease. The symptoms were characteristic of an irritant poison, and they were able to discover no other probable cause for those symptoms than that which the deceased had alleged, persistently and exclusively, from first to last, viz., the inhalation of concentrated vapours in passing the manure work, and designated by him at the moment, and repeatedly before his death, as "that horrible smell." Afterwards, and while yet every detail was fresh in the memory, and every correlative circumstance could be recalled and, if need were, investigated or substantiated, the case was considered in confidential counsel by the medical attendants, together with Dr. Littlejohn, Dr. Dunlop, and myself. Dr. Mackay is Medical Officer of Health and Police Surgeon for Inverness, and besides the qualifications and experience connected with such offices, he has, to my knowledge, an acquaintance with the pathology and chemistry of poisons much beyond the average of medical practitioners. Dr. Wilson, as a consulting physician, and as the consulting medical officer of the principal public institutions of Inverness and neighbourhood, holds admittedly a position second to none in the north of Scotland. Dr. Littlejohn is Medical Officer of Health and Surgeon of Police for Edinburgh, and he is Lecturer on Medical Jurisprudence in the College of Surgeons' Medical School. His experience and opportunities are immense, and he is necessarily required to advise with counsel, to uphold in the witness-box, and to unravel in the lecture-room the connections of cause and effect in obscure cases of illness and death. Dr. Dunlop, the Andersonian Professor of Surgery, is the Medical Examiner in Criminal Cases for Glasgow and County of Lanark, and was for some years Assistant Medical Officer of Health for Glasgow. He has therefore been trained to form opinions in medico-legal cases with all the guarded caution that official responsibility inculcates. Regarding my own opportunities, I may be excused for stating that, as confiding friends and colleagues, the late Dr. Penny and myself rendered mutual aid and counsel in nearly all the very numerous sanitary and medico-legal cases with which either of us were concerned during a period of twenty-five years. Our joint-investigation in the case of Dr. Pritchard, where Dr. Penny's chemical enquiries shewed that the death of Mrs. Pritchard was due to the mineral poison of antimony, while my physiological experiments demonstrated the curiously complicated mode in which the criminal destroyed his other victim, Mrs. Taylor, with aconite, is one illustration of the manner in which Dr. Penny and myself combined and shared our labours. Each individual of the conference on Mr. Fraser's case had a medical experience exceeding twenty years, and the special fitness of such a jury cannot well be gainsaid. It is surely in determining the limits of imagination in the production of physical results that professional knowledge may claim some deference, and speak with the voice of authority. We discussed Mr. Fraser's case in all its bearings. We had no difficulty in conceding that imagination and mental excitement are important influences, and that either is quite sufficient to cause bodily illness, even to death. Daily experience furnishes instances so frequent, indeed, that from their customary effects we can predict the several modes in which they will act. Whenever, from any cause, the passions are permitted to overrule the reason, disease is the result. Intense sudden excitement or prolonged and apprehensive anticipation of coming evil may cause a nervous paroxysm in which the individual will expire, the victim of his own passions. A blood vessel may rupture; hysterical, or hypochondriacal, or dyspeptic symptoms may cause suffering and anxiety, or the reason may be overthrown. But under no circumstances will mental excitement and imagination produce the connected and complete range of symptoms characterising a well-known irritant poison. No more will they produce the symptoms affecting Mr. Fraser than they will produce small-pox or club foot. To believe otherwise would be to ignore all that common observation, modified by physiology, can teach. We were satisfied that the conditions of advanced age and of the nervous shock caused by the inhalation of disagreeable and dreaded effluvia, were important factors, and had aided materially the depressing influence under which the sufferer succumbed. We therefore by no means attributed the fatal result to arsenic alone. We were satisfied that if there was to be anything like a real explanation of Mr. Fraser's symptoms, it must be sought *in that aggregate of conditions* out of which they had arisen. In short, we were of opinion, as was also the magistrate who pronounced upon the case, that common sense and special professional knowledge alike directed clearly to the conclusion that the immediate symptoms and fatal result were due essentially to *irritant poison or poisons*, and that *those poisonous influences were contained in the manure vapours.*

In conclusion, I have no feeling inimical to manure manufactories. On the contrary, my sympathy and services have on several occasions been with the proprietors. I regret that there should exist any necessity for the frequent complaints and almost ruinous interference and litigation to which this legitimate industry is exposed, because I am well satisfied that thoroughly efficient remedies for the evils it occasions have already been, and therefore can be again, applied. And I think it would be matter for congratulation to be offered to the manufacturer if, through legislative enactment, they were placed under such judicious regulations as would leave a free margin within which they would be protected from public opprobrium or legal penalties. But it is only by authoritative disposition of working arrangements—only through a general coercive remedy from without the trade—that the manure manufacturer is likely to have peace, and the public protection. The Alkali Act of 1869 is an illustration of such a remedy. This Act renders it imperative that all manufacturers decomposing common salt for the production of sulphate of soda should condense not less than 95 per cent. of the hydrochloric acid gas evolved by such decomposition. This Act was urgently called for, owing to great public inconvenience and injury arising from the operations of such manufacturers. The Act works excellently well; it has been profitable to the manufacturer, and it has freed him and the public alike from annoyance. The remedy was simple, and it proved thoroughly effective. There is a close analogy in the conditions now affecting the public through the operations of manure works; and, as there was in the alkali trade, so is there now in the manure trade, little of remedy to be obtained from within. But, unless in exceptional instances, all suggested reform will be met with the "*laissez faire*" cry of a threatened interest. Meanwhile, it is all the more necessary that the manure manufacturer, his skilled defenders, and the general public should learn—what I am now attempting to teach—that there is a substantial basis of fact underlying the popular instinct which associates bad odours with apprehended danger to health and to life itself; and that it is a great error and a mistaken policy that attributes all complaint to "over-fastidiousness" and "effects of imagination."

ADDENDA.

Proposition Second, p. 35.—The pyrites in common use are nearly on a par in the proportion of sulphur,* averaging from 47 to 49 per cent., which fits them for the production of sulphuric acid. But they differ in the average amount of copper, of silver, and of arsenic which they contain. They also differ somewhat in their behaviour while being roasted to drive off the sulphur in the process of vitriol making, but this distinction is appreciated only by the acid manufacturer. Thus an experienced maker informs me that he prefers the Seville Company's pyrites, because they burn better and give fewer "smalls" than most others in the market. On the other hand, they contain considerably more arsenic than the average, and this excess is communicated to the sulphuric acid. In all manufacturing operations where the arsenic contained in sulphuric acid can enter into and affect the quality of the article manufactured, or where the arsenic can be volatilised and pass into the atmosphere, the extent of arsenical contamination of the sulphuric acid is a matter of considerable importance. It affects the interests of the manufacturer, and it also affects the public health. I have therefore constructed a table, which brings out the differences as regards arsenic which exist in the pyrites of the three large companies that furnish the greater part of the staple material of sulphuric acid manufacture.

Arsenic exists, or rather *is estimated* as existing, in pyrites, *in the form of a metal.* But when the pyrites are roasted, metallic arsenic is volatilised, takes oxygen from the atmosphere, becomes thereby much larger in bulk and in weight, and is converted into white arsenic, *i.e.*, arsenious acid. It is in this state of increased bulk and weight that arsenic enters into sulphuric acid, where it is liable to undergo the higher oxidation, and be converted into *arsenic* acid, with a still farther increase of bulk and weight. The calculations in

* According to the analyses of Mr. Gibb (Year Book of Facts in Science, 1875, p. 106), the *pyrites* of the three principal companies contain on an average:—

	Rio Tinto.	San Domingo.	Tharsis.
Sulphur, ...	48·0	48·0	48·0
Copper, ...	3·80	3·70	3·50
Silver, ...	1·20	0·75	0·75
Arsenic acid *in the cinders* or "*burnt ore*,"	0·24	0·25	0·17

the subjoined table only follow the change into arsenious acid, but the basis of an extended estimate for *arsenic* acid is given at page 34. As in preceding tables, I have converted percentages into tons and pounds weight, and I have otherwise endeavoured to shew how the entire arsenic is disposed of, by arranging the results of the most important stages of sulphuric acid manufacture in such a manner that they can be comprehended and contrasted at a glance.

	Rio Tinto.			San Domingo.			Tharsis.		
Percentage of *Metallic* Arsenic in Pyrites, ...	0·56			0·47			0·40		
	Tons.	*cwts.*	*lbs.*	*Tons.*	*cwts.*	*lbs.*	*Tons.*	*cwts.*	*lbs.*
Metallic Arsenic in 100,000 tons of Pyrites, ...	560	0	0	470	0	0	400	0	0
Arsenious Acid in 100,000 tons of Pyrites, equal to	739	4	0	620	8	0	528	0	0
Do. *volatilised* from 100,000 tons of Pyrites in making 140,000 tons of Sulphuric Acid,	537	7	108	450	18	73	383	17	13
Do. *retained* in the cinders of 100,000 tons of Pyrites, ...	201	16	4	169	9	39	144	2	99
	Lbs.	*ozs.*	*grs.*	*Lbs.*	*ozs.*	*grs.*	*Lbs.*	*ozs.*	*grs.*
Arsenious Acid in each ton of Pyrites, ...	16	8	407	13	14	154	11	13	103
Do. *volatilised* from do., ... 51·1 °/₀	8	9	251	7	3	203	6	2	117
Do. *extracted* from each ton of Sulphuric Acid, ... 21·6 °/₀	2	11	79	2	4	107	1	14	370
Do. *retained* in the cinders of each ton of Pyrites, ... 27·3 °/₀	5	4	77	4	6	281	3	12	53
100·0 °/₀									

It appears, therefore, that 21·6 per cent., or, in round numbers, more than one-fifth part of all the arsenic contained in pyrites, passes into, and is retained in, the sulphuric acid. I have already explained how it is that this average estimate may frequently exceed or fall short of the actual amount.

Proposition Fourth, p. 41.—An absolutely pure sulphuric acid may not be required for many manufacturing operations. But it is of prime importance that manufacturers should recognise, in a manner not hitherto done, the fact that, in the arsenical contamination, there is a potential element of danger, as illustrated in the present enquiry. And acid manufacturers should not continue, as at present, to employ the very crudest processes, seeing that, with extremely little cost, these processes may be modified, with the result of effecting a very great improvement in the quality of the acid. I have seen and tested such a simple modification, resembling somewhat the process of M. Oliver. In this process the gases disengaged from the burning pyrites are carried along a tortuous flue, in an up and down manner, a portion of the flue, 20 or 30 feet long, consisting of an iron pipe immersed in water, and ending in a precipitating chamber, in connection with the leaden chambers. By means of this arrangement, the gases and metallic fumes are cooled, and a considerable deposit of solid particles takes place before they enter the vitriol chamber. This deposit has been analysed by Mr. R. C. Clapham, and found to consist of, in round figures, 59 *parts of arsenious acid*, 8 parts of iron, lead, copper, zinc, and sand, and 33 parts of sulphuric acid and water.

Proposition Sixth, p. 43.—Among professional or manufacturing chemists there is one gentleman of admitted pre-eminence for his scientific skill and unapproached practical experience in all that concerns the chemistry of artificial manures. He is thus referred to in the latest edition of the English Cyclopædia:—"Mr. J. B. Lawes, of Rothamsted, Hertfordshire, who has lately sold to Lawes' Chemical Manure Company his manure manufactories, &c., for £600,000, is generally considered the father of the chemical manure trade." It is with extreme gratification that I cite him as the most important witness to the accuracy of my whole argument. Nothing in the way of corroboration could be more complete, full, and authoritative than the following letter. The more important passages I have given in italics.

To Dr. Adams,
Glasgow.

Rothamsted, St. Albans,
August, 1876.

Dear Sir,

Pray accept my thanks for your pamphlet, which I have read with a great deal of interest. Since 1872 I have entirely ceased to have any interest in the commercial manufacture of manure, but for thirty years previous to that I made probably more artificial manure than any one else. *By far the largest amount of soluble phosphate is made from mineral phosphate containing large quantities of fluoric acid, and I think the amount of chamber acid is considerably more than you name.* With Cambridge coprolites I used equal parts acid and coprolites; with Charleston phosphate, 70 to 80 per cent. All the acid made is derived from Spanish or Portuguese pyrites. *It is quite certain that arsenic is given off in considerable quantities in the vapours.* To avoid nuisance, I erected a large factory at Barking Creek. The soil there is very wet, and the land below high water in the Thames. The few people who lived there were martyrs to ague, and the workmen employed in erecting the factory were always suffering from it. After the works were established this complaint entirely disappeared, and I always fancied that the diffused vapour of arsenic might account for the change. *What fresh diseases were created, or how far the general health of the men was affected, I am not able to say.*

The largest part of the pyrites imported is used by alkali makers, and although they are compelled to condense their hydrochloric acid, still this acid is used, and *ultimately, I think, the bulk of the arsenic must find its way into the atmosphere.*

There can be no doubt that, by running the mixture of phosphate and acid into closed chambers, as was done at my works at Deptford, and passing the vapour through a large fire and then through a tower of wet coke, that much organic matter was burnt, and arsenic and fluoric acid were condensed; still, smells will be generated, and the great point is how to reduce the evil to a minimum without injuring or destroying an important branch of trade, or so far interfering with it as to increase the cost of the product to the consumer.

I am, &c.,

J. B. LAWES.

Mr. Lawes shews that I have much understated, and not overstated, my case, his vast experience enabling him to point out, as a mere matter of fact, that by far the largest amount of artificial manure is made from those materials that evolve arsenic in greatest abundance, viz., coprolites or mineral phosphates. He has drawn from his exceptionally great experience a shrewd deduction, which will be read with great interest by medical men, for it so happens that, next to quinine, the chief remedy for ague is arsenic. That arsenic is largely given off from chemical manure, and that the chief bulk of the arsenic contained in sulphuric acid must find its way into the atmosphere under existing arrangements, is to Mr. Lawes an accepted fact. I cordially endorse his concluding remarks; they are in perfect accordance with my sentiments, as already expressed at the close of my pamphlet.