REPORT

ON THE

EXPLOSION OF GUNPOWDER IN THE REGENT'S PARK

ON THE

2ND OCTOBER 1874.

BY MAJOR MAJENDIE, ROYAL ARTILLERY, H.M.'S INSPECTOR OF GUNPOWDER WORKS.

Home Office, Whitehall,
1st June 1875.

SIR,

I HAVE the honour to furnish the following Report on the Explosion of Gunpowder which occurred on board a canal boat belonging to the Grand Junction Canal Company in the Regent's Canal, Regent's Park, London, on the 2nd October 1874, by which three lives were lost, and a considerable amount of property was injured.*

I received the first information of this accident about a quarter past 9 a.m. the same morning by a messenger from the Chief Commissioner of the Metropolitan Police, and I proceeded as soon as possible to the spot to investigate the circumstances of the accident.

I was thus enabled to examine the scene and neighbourhood of the explosion within a few hours of its occurrence, and I continued my observations on the following day, and on subsequent occasions. In company with Mr. Hughes, the traffic manager of the Grand Junction Canal Company, I also visited the wharf, and examined some of the boats of the Company; and I obtained from Mr. Hughes, and from other witnesses, information as to the circumstances, and the cause of the accident. On the 7th October, having, as stated in my report of that date, formed in the course of my inquiry "a tolerably confident opinion as to the true cause of the accident," I applied for your permission to engage the services of "some chemist of eminence who has specially "studied the particular matters to which his attention and evidence would in this case "require to be chiefly directed," and for this purpose I named Mr. T. W. Keates, consulting chemist to the Metropolitan Board of Works, a gentleman who having made a special study of and obtained a large practical acquaintance with petroleum and its products, appeared to me to be specially qualified to assist in the elucidation of an explanation of the accident, which I foresaw from an early stage of my inquiry would hinge upon the possible or probable behaviour of the more volatile descriptions of petroleum under a particular combination of circumstances. I obtained your sanction to Mr. Keates employment, and received from that gentleman all the assistance which I could desire.

I desire also to take this opportunity of recording my obligations to Professor Abel, F.R.S., of the Royal Arsenal, for the valuable assistance which he afforded me in carrying out my investigations into the cause of this accident, and especially for suggesting to me and assisting me to arrange certain experiments, with a view to demonstrating evidentially the true explanation of the accident.

From Major Ford, also, who met me in London on the 3rd and 5th October, and worked with me on those occasions, I received material assistance.

It is also proper that I should state that the Grand Junction Canal Company showed every readiness to afford me information and assistance in prosecuting my inquiries.

The inquest was opened at the Board Room of the Marylebone Workhouse, Northumberland Street, Marylebone Road, by Dr. Hardwicke, then Deputy Coroner for the

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* It is a curious coincidence that this explosion occurred as nearly as possible on the tenth anniversary of the great Erith explosion (1st October 1864), and that almost exactly 10 years previously (6th October 1854) the great Gateshead explosion had taken place. Nor does the coincidence end here, for a record of explosions shows that the month of October has been exceptionally fruitful in such disasters. Thus, in October 1866 a quantity of experimental guncotton exploded in Woolwich Arsenal; in October 1867 a serious cartridge explosion occurred at the same place; in October 1868 the Great Barnsley firework explosion occurred; and on the 1st October 1869 the Notting Hill explosion occurred, while in the same month a guncotton magazine was destroyed in Cornwall, and a serious explosion took place in the Blackbeck Gunpowder Works.

Central District of Middlesex, on the 3rd October, and was continued on the 7th, 12th, and 19th October.

The Regent's Canal Company and the Grand Junction Canal Company were represented by counsel.

The information collected by me in the course of my inquiries, coupled with my personal observation and experiments, together with the evidence given at the inquest, furnish materials for the formation of a thoroughly reliable opinion as to all the attendant circumstances of this disaster, and enable its cause to be assigned with an exactness and confidence which are unusual in cases of explosions.

Frequently in such cases the explanation ultimately arrived at after the most patient investigation is more or less inconclusive, being reached only by a process of weighing together the various possible explanations and eliminating the more improbable.

In the present instance, happily, no such uncertainty prevails. The explanation of the accident is no matter of opinion or balanced probabilities, but may, as I venture to think, be demonstrated with strict and logical accuracy.

It will be convenient in treating this subject to arrange it under four heads, viz. :—

1. Site, nature, and circumstances of the accident.
2. Destructive effect.
3. Cause of accident.
4. General remarks.

1. *Site, Nature, and Circumstances of the Accident.*

Site of accident.

The site of the explosion was the Macclesfield Bridge, Regent's Canal.

This bridge crosses the canal at the north gate of the Park, and runs in a direct continuation of Avenue Road, and towards the Baptist College, which lies 450 feet distant from the south-east end of the bridge.

The Regent's Canal, which was opened for traffic in 1820, was constructed under 52 Geo. 3. c. 95. and 53 Geo. 3. c. 32. ;* it has its starting point on the Thames at the Limehouse Dock, and passes through Stepney, Mile End, Bethnal Green, Shoreditch, Islington, St. Pancras, Marylebone, and Paddington, in which last-named parish it communicates with the Grand Junction Canal. The total length of the canal from the Regent's Canal Company's Dock at Limehouse to its junction at Paddington with the Grand Junction Canal is about 8½ miles. (Its course is shown by Plate A., the scene of the explosion, about 7½ miles from the commencement of the canal, being indicated on this plan by a cross.)

This canal is united to the River Lee by the Hertford Union Canal (or as it appears to have been once called "Sir George Duckett's Canal"), also belonging to the Regent's Canal Company, which skirts the south-east boundary of Victoria Park, and connects it with the Regent's Canal at the south angle of the Park, about 1¾ miles from the Company's Limehouse Dock. The canal is stated by the Company to be navigable for barges of 100 tons burden, and it is open to barges and boats navigating the Thames, River Lee, and Grand Junction Canal, and forms an important artery of communication between the districts served by these waters.

The Company themselves do not act as carriers, but simply as owners of particular docks and canals, into which all barges and boats on payment of toll have a right to enter. Indeed, it was stated by the Company's counsel that the Company, in virtue of 52 Geo. 3. c. 195. s. 67., were compelled to carry any barge or boat which might present itself, irrespective of the nature of its cargo, or of the arrangements made or neglected to be made for its safe protection.

This is a point of law upon which I shall not pretend to express an opinion, but as bearing upon this subject, and as apparently indicating an opposite view on the part of the Company so recently as 8th February 1872, I beg to quote an extract from a letter of that date from the General Manager of the Company to my late assistant, Captain Smith, R.A., in reply to some inquiries which that officer had, at my request, addressed officially to the Company :—"In reply I beg to acquaint you that this "Company have no *published* rules applying to the conveyance of gunpowder on their "navigation, but instructions are issued to their officers not to permit any vessel having "on board gunpowder to enter the navigation, unless the cargo portion of the vessel "is completely enclosed with tarpaulins, also a red flag hoisted in a conspicuous "position on the vessel, and all fires and lights extinguished, smoking also being "strictly prohibited."

* Other Acts applying to the canal are 56 Geo. 3. c. 85. and 59 Geo. 3. c. 66., and under these and the Acts named in the text the navigation has been maintained.

It will presently appear either that the Company had given up this system of supervision and control, or that their officers had neglected their instructions, for it is clear that, from whatever cause, these salutary regulations were not observed at the time of the accident, and from the evidence at the inquest it would appear that they had not been observed for some time previous. It will further, I think, be clear that had these instructions been strictly enforced this explosion would not have occurred.

Among those who largely employ the Regent's Canal are the Grand Junction Canal Company, who despatch and receive a number of boats daily by this route.

The principal business of loading and despatching the boats of the Grand Junction Canal Company appears to be carried on at some extensive wharves at the City Road Basin. This basin is situated at a spot on the Regent's Canal, four miles from the Limehouse Dock and about three and a half short of the site of the explosion. It was at the City Road Basin that the boat on board which the explosion occurred was loaded on the evening previous to the explosion, and it left the wharf, in company with some other boats, to be hereafter more particularly described, soon after 2 a.m. on the 2nd October, laden with a cargo for the Midland Counties.

The boats employed by the Grand Junction Canal Company on this service, are technically known as "fly-boats." They are long, narrow, flat-bottomed boats, 70 feet in length, about seven feet beam, and four feet two inches deep from gunwale to bottom.

In the bows of the boat is a small bunker, about eight feet long, and furnishing stowage accommodation for coals, &c. At the stern of the boat is a small cabin, about nine feet long, which rises two feet above the gunwale, and is about five feet wide at the top. The vessel is steered from behind the cabin, the stern being decked over at this part on a level with the gunwale, and from this position the steersman can see over the cabin and over the whole length of the boat.

The cabin is provided with a stove, and lamps (supplied by the men) are generally used to give light. The cabin is separated from the stowage portion of the vessel by a wooden bulkhead, having in it a hole or opening for ventilation of the cabin. In some of the boats which I examined this hole was lozenge shaped, with a sliding shutter. In others the hole was round and without any shutter. In some barges, also, the bulkhead appeared to be fairly close and tight fitting, but this was not the case with all the barges that I inspected. And it is, at any rate, clear that no bulkhead having a hole in it for ventilation, whether closed by a sliding shutter or not, can be regarded as hermetically secured. As the boat on board which the explosion occurred had certainly a ventilator opening of one sort or another, this point will presently be found to be of importance.

The cargo is stowed in the space between the cabin bulkhead and the bow bunker, 45 feet 9 inches in length.

This space is divided into four portions, distinguished technically as "fore end," "mast plank," "middle plank," and "stern end," and of a tonnage respectively of about four, six, six and seven tons. These divisions are not separated by any partitions or bulkhead, but are merely the spaces between the upright posts which support the horizontal planks by means of which the bargemen pass from one end of the boat to the other. The method of covering and securing the cargo on board these boats consists in making fast the "side cloths" (which are permanently fixed to the gunwale) by cords to the top plank, and then laying the tarpaulins (or "top cloths") over all, and making them secure with ropes. (Plate B. shows the details of one of these boats.)

Each fly-boat was usually managed by a "captain" and two bargemen (engaged by the captain).

Nature and circumstances of accident.

On the morning of the 2nd October, soon after 2 a.m. five "fly-boats," which had been loaded and "clothed up" over night, left the City Road Basin in tow of the steamboat "Ready."

The boats were in the following order :—

1st. "Jane,"	in charge of a man named	Boswell.
2nd. "Dee,"	" "	Edwards.
3rd. "Tilbury,"	" "	Bexson.
4th. "Limehouse,"	" "	Hall.
5th. "Hawkesbury,"	" "	Blewer.

These vessels carried mixed cargoes, of which it will be sufficient to observe for the present that it appeared from the evidence at the inquest that of the five boats four had consignments of gunpowder on board, viz., the

"Jane,"	"Tilbury,"
"Dee,"	"Hawkesbury,"

and of these four all except the "Jane" had petroleum on board in addition.* The steam-tug "Ready" also had two casks of petroleum on board.†

The petroleum on board the several boats seems to have been of various descriptions, but it is certain that the "Dee," "Tilbury," "Hawkesbury," and the steam-tug had on board one or more cases of the most volatile descriptions of petroleum, viz., benzoline and naphtha.‡ Of the character of these oils, or more properly spirits, it will be necessary to speak more particularly hereafter. The cargo of the boat "Tilbury" will also call for special observation further on.

The boats were attached to each other by ropes in the order stated, intervals varying from about 10 to 20 yards intervening between every two boats.§

The boats seem to have proceeded without anything unusual happening until they had traversed about three and a half miles of the canal, and were passing through the Macclesfield or North Gate Bridge, a little before 5 a.m. At this point there occurred on board one of the boats a sort of slight preliminary explosion, or rapid burst of blue flame,‖ or, as one of the witnesses described it, a "blue bursticle." Three witnesses speak positively to this burst of flame or light having issued from the centre boat, the "Tilbury."¶

This occurrence not unnaturally caused some excitement on the part of those who witnessed it, and word was immediately passed to stop the steam-tug. It is not quite clear whether the order to stop the steamer was given by the steerer of the "Tilbury" (deceased), or by William White, the steerer of the "Dee."

William White, whose evidence is very important because he was nearer to the "Tilbury" than any other survivor, informed me that what passed was as follows:—

"On seeing the burst of flame, *which seemed to come out of the hatches*" ("it catched "fire at the stern end"), he hallowed out to the steerer of the "Tilbury," "What have "you got up in that boat; you've got some powder on board" (or "something is gone off "in that boat.") He was unable to speak positively to the exact words. The steerer of the "Tilbury" answered, "I'm very nearly blown out of the hatches already."** White further stated that he (White), directly these words had passed, halloaed out "Stop her" to the steamer, and the man in the "Jane" halloaed too.††

Francis Clarke (steerer of the "Ready") said, "They had passed the bridge, and the "boats were coming through, when some one shouted 'Stop.' That came from some of

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* The quantities of powder were stated to be as follows:—

"Jane," about $\frac{3}{4}$ ton; "Dee" ($1\frac{1}{2}$ cwt.); "Tilbury," over 5 tons; "Hawkesbury," 24 casks.—The evidence of Mr. Hughes, 7th October, and captain of "Dee." 12th October.

† Evidence of Mr. Hughes, 7th October, and captain of "Ready," 7th October.

‡ Mr. Hughes stated (evidence of 7th October) that the "Dee" had on board "one case of naphtha, one "barrel of petroleum, and another in a different name entered as 'paraffin.'" Also two cases of "spirits," "and the carriers do not know what that means." The "Tilbury" had on board "one cask of petroleum "..... and four barrels of benzoline." The "Hawkesbury" had on board "some pipes of oil, a barrel "of oil, a barrel of benzoline, four casks of 'spirits.'" The "Ready" had "two barrels of benzoline."

§ It is not very easy to say precisely what this interval was in each case. Not only were the ropes of different lengths, but they were not always out to their full length.

The captain of the "Limehouse" (Hall) told me that he thought he was only about 10 yards astern of the "Tilbury." I measured the rope which had been used, and it gave a length corresponding to an interval of about 13 yards.

‖ Evidence of Francis Clarke (steerer of the "Ready"), 7th October 1874.
Do. John Boswell (do. "Jane"), 12th October 1874.
Do. William White (do. "Dee"), 19th October 1874.

The last named witness in reply to some questions I put to him in the hospital on 5th October informed me that he heard a puff, saw a little light, and heard a noise like the sound of a gun, but muffled; and he subsequently described it as a "lift of light" with a "bit of noise," but without any smoke. The light, he said, "seemed to lighten very nearly the breadth of the canal." This man's evidence is particularly important as he steered the boat immediately in front of the one which exploded. He gave me a much clearer account in hospital than he subsequently gave at the inquest, when he seemed nervous and too ill to speak circumstantially. At the trial in the Common Pleas this witness gave his evidence with great reluctance, and denied having seen any light or flash.

The captain of the "Limehouse" (Hall) also stated that he saw what he believed was a flash of lightning "about two minutes and a half before the explosion."—Evidence of 7th October 1874.

¶ "It was on the 'Tilbury,' he was sure of that."—Evidence of Francis Clarke (steerer of the "Ready"), 5th October 1874.

"That was on the 'Tilbury.'"—Evidence of John Boswell (steerer of the "Jane"), 12th October 1874.

"That was on the 'Tilbury.'" "He was just looking at the boat at the time." "It seemed regularly to "lighten above the cabin." "It came from the cabin, somewhere near the cabin, as near as he could place "it."—Evidence of William White (steerer of the "Dee"), 19th October 1874.

See note above as to the evidence of this witness in the Common Pleas.

** Substantially White gave the same account to the coroner's jury on the 19th October, but less circumstantially than he related to me personally in the hospital.

†† White's evidence before the coroner's jury was as follows:—"The chap shouted to stop the engine."

" the boats behind, but which he could not tell. . . . . They shouted out 'Stop,'
" this boat's afire."*

John Boswell (steerer of the "Jane") said, "He first heard a man call out 'Stop her.'
" . . . . The voice which said 'Stop her' came from the 'Tilbury.' . . . . .
"They could not see anyone on board the 'Tilbury,' but he knew the voice of the
" steerer, and heard him say 'Our boat's afire.'"†

Thomas Boswell (captain of the "Jane"), who was lying down in the cabin, "heard
" some one say 'Stop her.' It was one behind, but whether in the second or third boat,
" or in the one next to his own, he could not tell."†

John Edwards (captain of the "Dee") was taking his shoes off in the cabin, was called out by the steerer White, who said, "Jack, look here, there's something up on
" board of Bexson's boat (the 'Tilbury'). Some one shouted out 'Stop.'"†

Whether therefore the order to stop the steam-tug proceeded from the steerer of the "Tilbury," or from the steerer of the "Dee," or, which is perhaps the more probable, from both, it is certain that this order was given.¶

It is equally beyond dispute that the order to stop her was attended to. Francis Clark (steerer of the "Ready"), said, "As soon as they said 'Stop' he rang the bell
" to stop her, and the engine was stopped dead."*

William White said, "The engine did slack,"‡ and the fact that there was a sensible slackening of the progress of the little fleet is indirectly supported by the evidence that in a brief interval of time an order came to "Go on ahead." It seems certain that this order came from the steerer of the "Tilbury." John Boswell (steerer of "Jane") said,
He heard a voice which said 'Go on,' and that came from the 'Tilbury' too."†

John Edwards (captain of "Dee") said, "He heard some one say 'Go ahead.' . . .
" The one who said 'Go ahead' was behind; he was hanging on to them."§

William White (steerer of "Dee") said, "There was time after and before the great explosion to shout 'It's all right, go ahead steady.' The chap who was steering the
" 'Tilbury' said that."‖

The steamer went on again, and almost immediately a terrific explosion occurred on board the "Tilbury," by which the "Tilbury" herself was destroyed, and the three men on board of her (Charles Bexson, William Taylor, and Jonathan Holloway) were killed; the "Limehouse" (immediately behind the "Tilbury") was sunk, the "Dee" (immediately in front of the "Tilbury") was damaged (the steerer, William White, being injured), the Macclesfield Bridge was destroyed, and damage done in the neighbourhood to an extent which will hereafter be more particularly described.

With regard to the exact interval of time which elapsed between the outbreak of flame on board the "Tilbury" and the great explosion, it is difficult to arrive at any very positive conclusion. I have found in the course of my inquiries into accidents by explosion that no reliance whatever can be placed upon the estimates formed by different observers as to the duration or extent of particular intervals of time in immediate connexion with the main event. The power of measuring time within a certain interval of an explosion, seems, if one may so say, to come within the scope of the destructive effects of the explosion itself, and to be annihilated thereby. The result is that some very striking discrepancies of statement on this point on the part of witnesses otherwise thoroughly reliable have come under my notice.

The present case forms no exception to what I have come to regard as the general rule, and we find the witnesses disagreeing seriously as to the interval of time which elapsed between the outburst of flame and the explosion.

If the "flash of lightning" which the captain of the "Limehouse" states he witnessed before the explosion was, as I am disposed to believe, really the burst of light from the "Tilbury," of which the other witnesses speak, then the interval between the two events was "about two minutes and a half."¶

Francis Clark (steerer of the "Ready"), speaking of this interval, said, "There did not
" seem any time at all," but he also stated that the interval was of sufficient duration for

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* Evidence of 5th October 1874.

† Evidence of 12th October 1874.

‡ Evidence of 19th October 1874.

§ The boat immediately behind the "Dee" and hanging on to it was the "Tilbury."—Evidence of 12th October 1874.

‖ Evidence of 19th October 1874.—Among the many remarkable incidents connected with this explosion, there is scarcely one more remarkable than the nonchalance of the man who having been nearly blown out of the hatches "by a sudden burst of flame" takes no trouble to discover whence the flames proceeded and what had occasioned it, and, notwithstanding the presence of five tons of gunpowder, merely says "Go on ahead."

¶ Evidence of 7th October 1874.

the engine to be stopped and to go ahead again; and further on he stated, "He should'nt "think it was hardly a minute when the explosion took place. . . . He did not "think it was so much as a minute."*

John Boswell (steerer of "Jane") thought the interval was "about two or three seconds," but it is doubtful from a subsequent statement whether he did not intend this estimate to refer to the interval between the order to "go on ahead" and the explosion.†

Boswell (captain of "Jane") estimated the interval at "a minute or a minute and a "half."‡

White did not assign any precise time for this interval, beyond observing that "there "was time after" (the engine slackened speed) "and before the great explosion to shout "'It's all right, go ahead steady.'"§

But indirectly this witness furnished a measure of the time by stating that the original flash occurred just as his boat "came up to the bridge,"‖ and the explosion when his boat was just leaving the bridge-hole and the "Tilbury" was just underneath the bridge.§

The width of the bridge (about 36 feet) may be taken as corresponding pretty nearly to the normal distance between the two boats when the tow rope was at full stretch, but this distance was no doubt diminished slightly from the slackening of the speed of the steamer, and it may therefore be assumed that it is quite possible for the steerer of the "Dee" to have been under the bridge at the same time as the "Tilbury" was actually entering the bridge. From the appearance of the ruins, and other circumstances to be hereafter dealt with, it is probable, I think, that the "Tilbury," if it was not about two-thirds through the bridge at the moment of explosion, was at any rate well underneath it,¶ and in this case the "Dee" would be entirely clear of the bridge. In any case, taking White's statement that the "Dee" had not passed through the bridge when the first flash occurred, and the established fact that the "Tilbury" had certainly not entirely cleared the bridge when the explosion occurred, it is clear that the interval of time which elapsed was a very brief one, and must be measured by seconds rather than by minutes; and it is doubtful if the whole interval sufficed to allow even the steamer to come to a complete standstill, while the boats behind continued no doubt to have more or less of "way" on them.

Conclusion as to circumstances attending accident.

We have thus a strong concurrence of testimony on the part of all those witnesses who were in a position to observe anything, testimony to which even if the three unfortunate men aboard the "Tilbury" had not been killed it is unlikely they could have added anything material, and which it is still less likely that they would in any way have negatived or contradicted.

This testimony appears to establish conclusively the following facts:—

1st. That the main explosion on board the "Tilbury" was preceded at a brief interval (probably something under a minute) by a sort of preliminary puff or muffled explosion accompanied by a vivid burst of blue flame without smoke from the cabin of the "Tilbury."

2nd. (*a.*) That this burst of flame was sufficiently remarkable and alarming to call forth strong comments from both the steerer of the "Tilbury" and the steerer of the "Dee," and to lead to the steamer being stopped because the "Tilbury" was believed to be on fire.

(*b.*) That the apprehensions thus momentarily excited were almost immediately allayed by the instantaneous disappearance of the exciting cause, and that the sudden flash was succeeded by a few moments of stillness during which the steamer again moved ahead.

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* "As soon as they said 'Stop,' he rang the bell to stop her, and the engine stopped dead, and they had time "to go ahead again with her before the explosion. They stopped just a short time like, and they saw nothing. "The blue flame disappeared, and it all went dark again. They went on. He should'nt think it was hardly "a minute when the explosion took place and all went up in the air together. He did not think it was so "much as a minute."—Evidence of 7th October 1874.

† Evidence of 12th October 1874.—When examined in the Common Pleas in the case of "Jackson v. The Grand Junction Canal Company," this witness stated that he did not recollect assigning a limit of "two or three seconds" between the first outburst of flame and the explosion.

‡ Evidence of 12th October 1874.

§ Evidence of 19th October 1874.

‖ White made a similar statement to me in hospital.

¶ John Boswell, steerer of the "Jane," stated distinctly in the Court of Common Pleas that the "Tilbury" was under the bridge when the explosion took place.

"3rd. That almost directly after the steamer had again begun to steam ahead the five tons of gunpowder on board the "Tilbury" exploded.*

These facts will become of considerable importance when I reach that portion of my report in which I deal with the cause of the explosion.

2. *Destructive Effect.*

I now proceed to consider the amount of destructive effect produced by this explosion. Destructive effect.

Explosions of large quantities of gunpowder in the middle of towns, or in the immediate neighbourhood of houses, are happily of comparatively rare occurrence, and it appeared to me desirable to take advantage of this accident to obtain all the data possible as to the effects produced under such circumstances. I considered that as we may hope that five tons of gunpowder will not again be exploded in London it was my duty to spare no pains to put on record all the facts relating to this remarkable disaster which it might be in my power to collect; and I have been the more anxious to do this, because a careful consideration of the special circumstances connected with this explosion have brought me to the decided conclusion that if five tons or any approximate quantity of gunpowder should happen to be again exploded in the metropolis, the effects are likely to differ materially from those produced upon this occasion, and to be far more considerable and destructive. Indeed, I believe I may confidently state that if the problem had to be set to any artillery or engineer officer, of exploding five tons of gunpowder in London at one time with the minimum of destructive effect, he could hardly have furnished a more satisfactory solution than that which by a remarkable concurrence of circumstances has been afforded by this accident; while if it had been also imposed as one of the conditions of the problem that the explosion was to be effected without killing or wounding any persons except those in immediate attendance upon the exploded gunpowder, and that although the explosion was required to be carried out in the immediate vicinity of masses of houses, and within a few feet of other considerable cargoes of gunpowder, none of these houses were to be blown down, none of their inmates were to be seriously hurt, and none of the other cargoes of gunpowder were to be exploded, and that this was to be accomplished on a highway running through the middle of the metropolis, and without any previous notice to the general public, I feel satisfied that there is no one who would not have regarded the problem as practically insoluble. But this is, in effect, what was done on this occasion, and these considerations combine to give an exceptional interest to the investigation of the particular circumstances under which this explosion occurred, and of the character and extent of destructive effect produced.

In addition to my own observations, carried out in company with Major Ford as soon as possible after the explosion, I have been fortunate enough to obtain valuable assistance from other quarters. The Chief Commissioner of Metropolitan Police was good enough to furnish me with a return from the various divisions of metropolitan police showing the distances at which structural damage was done, windows were broken, and the explosion was heard (*see* Appendix A.)

The Secretary of the Zoological Society furnished me with a report from the Superintendent of the injury sustained in the Society's gardens (*see* Appendix B.). I have had an opportunity of consulting the reports made to the Metropolitan Board of Works by the Superintending Architect and the Surveyor of the northern division of St. Marylebone; and the Committee of the Regent's Park Explosion Relief Fund having kindly placed at my disposal all the information in their possession, Mr. Ruthven Pym, on their behalf, permitted me to inspect the books showing in what cases relief was afforded, and thus enabling me to judge of the extent of damage; while from Mr. Hallett, who acted as surveyor to the Committee for the purposes of this fund, I have received valuable information respecting the streets and houses which were structurally affected.

The explosion, as has been already stated, occurred at and apparently under the Macclesfield or North Bridge.

* It does not appear to me worth while to attempt any proof that it was gunpowder which exploded on board the "Tilbury" and nothing else, for, although at first some suggestions were made that the material which exploded was nitro-glycerine or some other compound, the evidence as to the existence of a quantity of gunpowder on board the "Tilbury," more than sufficient to account for the damage which was done, all of which disappeared, in other words exploded, is conclusive; and, if the bills of lading are to be relied upon, there was nothing else of an explosive character on board the boat. If further proof as to the explosion having been a gunpowder and not a nitro-glycerine or guncotton explosion were needed, it would be furnished by the facts that the explosion was accompanied by dense volumes of smoke, and that all the trees, bushes, and other objects in the immediate vicinity and within the range of the direct blast were blackened with the exploded powder, and in some cases, apparently, bespattered with unexploded particles of the same.

I have already indicated the grounds upon which I base my belief that the "Tilbury" "if it was not about two-thirds through the bridge at the moment of the explosion, was, "at any rate, well underneath it."*

A careful examination of Plate C.† furnishes further evidence that the explosion occurred *under the bridge*, viz., the evidence afforded by the position of the two fallen trees marked 37 and 40, which both fell in such a direction as to prove that the forces to which they succumbed were directed from a point which is plainly indicated to have been about the bridge, towards which the trunks of the trees both converge.

The construction of the bridge (which is shown to some extent by Plate D.) is thus described in the "Engineer":—"The bridge consisted of two ranges of heavy cast-iron "columns, four in each, standing on the opposite margins of the canal upon stonework "on brick footings. Between the square caps of these columns small arches were formed, "on the upper surface of which the skew-backs for the three brick arches were "thrown, springing at either extremity of the bridge from brick abutments.

"The haunches above the arches were lightened by means of brick tubes about four "feet in diameter, open right through; all above the arches, with the exception of the "space occupied by these tubes, was filled in with hard rubbish, sustaining a macadamized "road 32 feet wide between the parapets, with narrow footways curbed and asphalted "on each side; the parapets were cast-iron railings. The supporting columns were very "massive castings, three feet five inches in diameter at the base, and were filled in solid "with brickwork. The height of these columns above the towing-path was about "14 feet 9 inches, to the level of the springing of the arches, which were segmental, and "the height from the water surface of the canal to the soffit of the centre arch at the "keystone was about 17 feet 6 inches."‡

The depth of the cutting through which the canal travels at this particular part is about 21 feet, measuring from the towing path.§ (The contours are shown on Plate E.)

It will thus be seen that the explosion occurred under exceptionally favourable circumstances; not merely were the lateral effects controlled and the forces deflected by the high banks which formed the side of the cutting,—these effects being doubtless further diminished by the lateral resistance offered by the water to the force exerted by so much of the powder as exploded below the water-line of the boat,—but a large portion of the force was absorbed in the destruction of a massive bridge.

The result was that the damage to surrounding property was of a far less serious and extended character than it otherwise would have been.

Structural damage.

Dividing the effects into structural and non-structural, I find that the former (*i.e.*, injuries to the fabric of the buildings) were confined to buildings in the following streets and terraces‖ (*see* Plate F.):—

Ormonde Terrace.
Lancaster Terrace.
St. John's Terrace.
× St. James' Terrace.
St. James' Mews.
×× Tichfield Road.
Barrow Hill.
×× Avenue Road (up to a point in prolongation of St. John's Wood).
Townsend Road (end towards bridge).
×× Tichfield Terrace.
×× North Lodge.
× Bentinck Terrace.
Frederick Street (east corner).
St. John's Wood Place.
St. John's Wood Terrace (one house, No. 67, structurally injured by debris projected against it by explosion).¶
Baptist College.

Of the foregoing, those marked ×× contained the houses which had suffered most severely, those marked × come next, and those not marked were the least injured.

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* *See* p. 6.

† This plan was made by the Royal Engineers.

‡ "Engineer," November 29th, 1874.

§ The difference between the centre of the Albert Road opposite the bridge and the towing-path is 21 feet, the road rising gradually in a north-east direction to 24; on the park side the ground is rather higher, the road opposite the bridge being 23 feet 6 inches above the level of the towing-path.

‖ I am indebted chiefly to Mr. Hallett and to personal observations for these particulars.

¶ This effect is recorded in the report of the Superintendent Architect of the Metropolitan Board of Works. A large hole had been driven through the upper part of the back of the house.

An examination of the area thus indicated will show that the structural damage to houses did not extend beyond 400 yards from the scene of the explosion.

If a circle with this radius be struck from the north bridge as a centre, it will, I believe, certainly cover every case of real structural damage; and, so far as really serious structural damage was concerned, this may be taken as indicated by the portion shaded red, or, roughly, within a radius of 200 yards from the point of explosion.* This conclusion agrees very well with the independent testimony of the police (*see* Appendix A.), who report that no structural damage occurred except in the S. (or Hampstead) division, and that there, with a single exception, the damage was limited to 400 yards.

The single instance was the "Eyre Arms" Tavern, distant 900 yards, a large portion of the ceiling of which is said to have fallen down after the explosion; but I would observe that injury to the plaster of a ceiling hardly comes properly within the term structural damage.†

Locally, of course, the havoc was very great, trees were blasted and blown down, railings were torn up and twisted, the bridge was destroyed, the North Lodge (distant about 30 yards) was almost blown down, and the banks and bushes were scorched and blackened for a distance of about 40 to 50 yards from the bridge, which may be taken as the extreme distance of the immediate effect of the blast, or "range of flash."

The "Tilbury" was of course completely destroyed, and the three men on board were killed.

The "Dee" (the next boat in front of the "Tilbury") was injured, the panels of the cabin being blown in, and the steerer was a good deal shaken and hurt. The "Limehouse" (the boat immediately behind the "Tilbury") was sunk, but the crew escaped without injury (the effects produced on the spot are best exhibited by the accompanying photographs.)‡

Damage to window sashes, doors, glass, &c.

When we endeavour to obtain an accurate estimate of the area within which damage of a less serious character than injury to substantial fabrics was produced, such injury as the destruction of window panes and sashes, the blowing open of doors, the breaking of plate glass windows, and shading off into the mere breaking of ordinary panes, the difficulties of precisely assigning a limit become greater, both on account of the enlarged difficulties of observation, and because effects of this sort are apt to be more capricious and abnormal, so that here and there a window will be found to have been broken or some injury of this class sustained at some altogether exceptional distance from the scene of explosion. For example, there is no doubt that a few windows were broken in the Langham Hotel, which is about $1\frac{1}{2}$ miles from the bridge, and the police record cases of broken windows up to $2\frac{1}{2}$ and even 3 miles (*see* Appendix A.) in Police Divisions E. (Holborn), S. (Hampstead), and Y. (Highgate).

Relief was also given by the Committee in streets removed by a very considerable distance from the scene of the explosion. (A list of the principal streets and places in which relief was bestowed is given in Appendix C., where also is given the Report of the Committee.)

But very many of these cases must be regarded as quite exceptional, and some of them might no doubt be explained if all the local circumstances were carefully considered.

From a very careful personal examination of the locality, in company with Major Ford, from the independent observations made by the Royal Engineer Officers attached to the Department of the Inspector of Fortifications, and from the information which I have derived from Mr. Pym and Mr. Hallett and other sources, I believe the area indicated by the dotted black lines on Plate G. substantially comprises the whole district in which any important effects in the way of broken windows were produced, while of course the space within which window frames and sashes, doors, and shutters were injured and ceilings were shaken down is very much smaller.

* "Some statements having been reported in newspapers very greatly exaggerating the structural damage "occasioned by the late explosion at Regent's Park, Mr. Peebles took means to ascertain the facts and found "that the injury referred to related more to locks and doors than to the external walls of buildings. "Mr. Peebles has sent a statement of the 14 cases in which he has had to take proceedings regarding "dangerous structures affected by the explosion. Two cases were found to be not dangerous; ten houses "were decayed and rendered more unsafe by the concussion; two houses were partly blown down." (Report of Superintending Architect of Metropolitan Board of Works.)

† A writer in the "Engineer," of November 27th, 1874, who evidently went carefully into this matter, but who assigns a less liberal construction to the expression "structural damage" than I have done, makes the area of such damage considerably less than that above recorded. This confirms me in the belief that 400 yards will amply cover all cases of what can properly be called "structural damage," and 200 yards all that can properly be called "serious structural damage."

‡ It has not been thought necessary to reproduce these photographs in this printed report.

Taking this area at its widest part, and where the force of the explosion was not broken by any intervening houses (viz., from the bridge across the Park to Park Square East and Park Crescent), the distance is just over a mile. Elsewhere a mile is far in excess of the distance at which this sort of damage was generally done, and three-quarters of a mile would perhaps more correctly represent the radius within which extensive damage was done in the way of broken glass, while the more serious injury to window frames, sashes, doors, ceilings, &c. may be safely regarded as limited (so far as my observation goes) to about 600 yards. It must, however, not be supposed that the breakage of windows, or the more serious injuries to frames, sashes, doors, and ceilings, were at all *general* over the areas indicated, any more than structural damage was *general* over the area assigned thereto. On the contrary, the effects, as is almost invariably the case in explosions, were most capricious; some houses comparatively near the scene of the explosion escaped almost uninjured, while others further off were structurally damaged; here a single pane only was broken, or a window entirely escaped, while another house far more distant presented the appearance of having been wrecked by a mob well supplied with stones,

To attempt to set forth in detail these various effects, a large number of which I noted down, would be to extend this Report indefinitely, and, as I venture to think, without corresponding advantage. Each case no doubt admits, when carefully considered, of some explanation; the house or windows which escaped had probably received some protection, directly by the interposition of surrounding objects, or indirectly by the deflection of the wave of atmospheric disturbance, or the house which had suffered so unexpectedly had, from its position perhaps, accidentally presented a sort of "breakwater" to the impinging wave, or had formed the point of contact of two opposing currents of force, or from local circumstances had been subjected to the full destructive effect of that partial vacuum which necessarily results from the sudden liberation of a large mass of non-permanent elastic gaseous products, and of gases momentarily enormously expanded by heat, or from the intensely rapid atmospheric disturbance which a heavy explosion produces.* All that can be attempted in this Report is to assign roughly the areas within which particular classes of effects were generally observable, or, rather, the areas beyond which those classes of effects were very rarely observable.

Summary of conclusions as to extent and nature of destructive effect.

And these areas may, I consider, be fairly set down as follows:—

		More roughly the figures may be taken at
Area of scorching effects, or "range of flash" -	50 yards	$\frac{1}{32}$nd of a mile.
Area of serious structural damage - - - -	200 "	$\frac{1}{8}$th
Area of structural damage - - - -	400 "	$\frac{1}{4}$th
Area of damage to window frames, sashes, ceilings, and doors -	600 "	$\frac{1}{3}$rd
Area of broken windows - - - - -	From $\frac{3}{4}$ mile to 1 mile	1 mile
Area within which the sound of the explosion was sensible -	15 miles†	15 miles

Serious and extensive as is the amount of loss, injury, and inconvenience indicated by the above figures, especially when it is considered that the various areas are closely built over and thickly populated, it is impossible to doubt that it is much less than could reasonably have been anticipated had it been known that five tons of gunpowder was going to be exploded in the middle of London. If any doubt existed on this point it would be at once removed by a comparison of the effects produced on this occasion by five tons, and the damage wrought by the explosion by Fenians of a single barrel (100 lbs.) of gunpowder at the Clerkenwell House of Detention on the 13th December 1867. On that occasion four or five persons were killed, over 40 were injured, a large number of houses (in Corporation Lane) were so shaken that they had to be pulled down, a considerable length of the prison wall, 25 feet high, and, in thickness, tapering from 2 feet 3 inches to 14 inches was blown down, and injury done to a large number of houses throughout the district.

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* Examples of the vacuum effect, if it may be so called, as exhibited by the "sucking out" of the doors and windows were numerous; but the most striking which came under my notice was at the Baptist College.

In this college there was a strong room, with no other opening than a door. The door was of thick sheet iron, and opened outwards. It was secured at the time of the explosion by a stout iron bolt, at least 1 inch × $\frac{1}{4}$ in section; the effect of the explosion was to suck the door out with such violence as to bend this bolt nearly double. Obviously, what had occurred was as follows:—A partial vacuum had become established externally, and the difference thus created between the atmospheric pressure upon the door outside and inside amounted to a violent internal pressure or blow.

† *See* Appendix A. There are one or two instances of the sound being heard at 17 miles, but these may be considered, like the broken windows at two and three miles, as abnormal.

The concussion at two and three miles was very violent, and one death (from premature confinement produced by the shock and alarm) certainly occurred at two miles (Holloway).

There can of course be no doubt that the *comparatively* restricted damage done on the present occasion was due to those special favouring circumstances to which I have before referred—the early hour in the morning, when few persons were about, the absorption of a large portion of the available force by the bridge, and especially the restriction of the lateral effects and the deflection of the forces by the high banks, and to some extent by the water surrounding the barge.*

What the consequences might have been but for these fortunate circumstances, *i.e.*, had the explosion occurred at almost any other part of the 24 hours, or of the boats journey through the canal (*see* Plan A.), can only be vaguely guessed at; but that they would have been of a most serious character, and might have involved a tremendous loss of life as well as of property, cannot, I think, be doubted.

3. *Cause of the Explosion.*

Cause of the explosion.

I have already expressed my opinion that the cause of the accident can be assigned with exceptional confidence, and I will now proceed to show in what manner the explosion, as I feel satisfied, most certainly occurred.

It may, however, be well to glance in passing at certain hypothetical explanations of the accident which have been suggested, or which presented themselves to me as more or less possible during the earlier stages of my investigation.

Two groups of possible explanations of accident.

The various explanations of the accident which it is possible to suggest may be grouped under the following heads:—

A. Causes external to the boat "Tilbury."
B. Do. internal do.

Causes external to the boat.

A.—*Causes external to the Boat.*

These may be enumerated as follows:—

(1.) Lightning, or silent electrical discharge.
(2.) Sparks.
(3.) Fire from adjacent conflagration or explosion.

Lightning.

(1.) With regard to the suggestion that the accident was due to lightning, this theory appears to me untenable in view of the facts.

(*a.*) That with one exception no testimony whatever has been forthcoming as to the existence of lightning at or about the time or neighbourhood of the explosion. The exception is Edward Hall, captain of the Limehouse, who, as already stated, affirmed that he saw a flash of lightning "about 2½ minutes before the explosion."† The circumstance that this evidence as to the existence of lightning at that time is not only entirely unsupported, but is directly contradicted by other witnesses,‡ coupled with the fact that there certainly did occur from another cause internal to the "Tilbury,"§ at a short interval before the explosion,‖ a sudden bright silent burst of light which might easily have been mistaken for lightning by a man in the act of going to bed, leaves me in no doubt, as I have before intimated, that Hall really did make this mistake, and that what he witnessed was not lightning at all, but the burst of light from the "Tilbury," of which mention has been already made.¶

(*b.*) That the explosion occurred at a spot where it would be *most unlikely* that any boat could be affected by lightning, still less a boat of the construction of the "Tilbury," and that it occurred on board the boat which of the five was, for a reason which I will state, the least likely to be struck. For the explosion occurred not on board a vessel with tall masts, sailing along—a prominent and solitary object—on the ocean, or over a

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* Of course, also, the protection afforded by the substantially built houses in front to the houses in rear contributed to minimize the effect, but this is not an exceptional circumstance, being one which would always be more or less present in a town.

† Hall (captain of the Limehouse) said "he saw a flash of lightning about 2½ minutes before the explosion. "He was then on the footboard just going to bed. He saw lightning during the night." (Inquest, 7th October.)

‡ Francis Clarke (steerer of "Ready") said, "It did not rain or lighten at all after they had started from the "City Road. . . . There was rain and lightning when they loaded in the afternoon, but he saw none in the night." (Inquest, 7th October.)

William Harding (captain of "Ready") saw lightning when they left the City Basin, but saw no lightning afterwards. (Inquest, 7th October.)

William White (steerer of "Dee") said, "I do not remember seeing any lightning" (Inquest, 20th October 1874.) This witness told me in hospital that he did "not remember seeing any lightning below the City Lock." (Private examination of 5th October 1874.)

§ *See* ante, pp. 4, 5, 6.

‖ *See* ante, pp. 5 and 6, as to the uncertainty of the exact duration of this interval.

¶ It is worthy of notice that this man was not called by the defendants as a witness in the trial in the Court of Common Pleas of "Jackson v. Grand Junction Canal Company."

flat plain, or upon an aqueduct, or under any one of those circumstances in which, as a prominent object in the landscape, it would of course have been liable to be struck. But this accident not only occurred to a canal boat the highest point of which was only about five or six feet above the water-line, passing through a cutting 21 feet high, and surrounded by high houses with the gas and water services in connection with the earth, and, overtopping all, the lofty chimney of the waterworks, provided with a lightning conductor, but the particular boat in question, as I have already shown, "if not about "two-thirds through the bridge at the moment of explosion was, at any rate, well underneath it.*

Now this bridge was built entirely of iron, and so would necessarily have furnished an exceptional protection to the boat underneath it.†

It appears to me, therefore, that to attempt to ascribe this accident to a stroke of lightning is to subject the probabilities of the case to a far more violent strain than they are capable of sustaining.

I assume of course that it is contended that the explosion was *directly* caused by lightning, and not merely that it was indirectly so caused by the previous setting fire by lightning of some petroleum on board, which burnt to the powder. The latter theory, although it would dispose of that part of the argument in the text which is based upon the fact that the explosion occurred while the boat was under the bridge (seeing that the original ignition occurred before the boat reached the bridge), would leave all the rest of the argument untouched, and would quite fail of the purpose with which the suggested explanation has been put forward, viz., the exoneration of the Grand Junction Canal Company from blame; for the fact would still remain that they were carrying benzoline with their gunpowder, and the hazard involved in such a mixed cargo would be rather emphasized if it were established that a stroke of lightning fired the benzoline, while it failed directly to fire the gunpowder, and would throw out into stronger relief the imprudence of carrying with the gunpowder something which possessed the property of easy ignition in so remarkable a degree. It is perhaps hardly necessary to observe that it could not be for a moment argued that the *gunpowder* was ignited by the lightning *before* reaching the bridge, and did not explode until the boat was under the bridge. Such an argument would involve the assumption that gunpowder once ignited would continue burning with accumulating intensity and volume until at last it culminated in an explosion, as guncotton or dynamite might do under certain circumstances.

On the other hand, if we assume the direct explosion of the gunpowder by lightning under the bridge, we shall still have to deal with the remarkable coincidence on board the "Tilbury" a few minutes previously of a fire or burst of flame of some sort. This has been placed beyond all doubt or question, and we shall still have to explain what the burst of flame was, how it was caused, and what became of it.

As regards the cognate theory, that the accident was caused by a silent electrical discharge, if by this is meant a discharge between the clouds and the earth (or water), this explanation, while it certainly disposes of the serious difficulty that no lightning was observed in or about the neighbourhood of the explosion at the time of its occurrence, leaves untouched the very substantial objection that the particular boat selected by the electricity was of all the five the least likely to be so affected, and was itself so situated as to be in fact exceptionally protected from any such effects.

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* *See* ante, p. 6.

† It is a well-known fact that a body enclosed in a stout metallic case is absolutely secure against a stroke of lightning. Sir Wm. Snow Harris observes on this point: "If a building were metallic in all its parts, an "iron magazine for example, then no damage could possibly arise to it from any stroke of lightning which has "come within the experience of mankind; e.g., a man in armour is safe from damage by lightning." (Sir Wm. Snow Harris' Memorandum on Use and Construction of Lightning Conductors. War Office Circular, 260, 25th May 1858; also War Office Circular of 1st May 1875.) And I am informed that it was a favourite experiment at the Polytechnic to put a small bird, a white mouse, some gunpowder, and a delicate electroscope under a wire gauze dish cover, and pour a torrent of powerful electrical discharges upon it, without any of the animate or inanimate objects being affected in the slightest degree.

In Deschanel's "Electricity and Magnetism" (English edition, edited by Everitt), p. 527, § 421, the following passage bearing upon this point occurs:—"*No force within a conductor.* When a hollow conductor is "electrified, however strongly, no effect is produced upon pith balls, gold leaves, or any other electroscopic "apparatus in the interior, whether connected with the hollow conductor or insulated from it, provided in the "latter case that they have no communication with bodies external to the hollow conductor. Faraday "constructed a cubical box, measuring 12 feet each way, covered externally with copper wire and tinfoil, and "insulated from the earth. He charged this box very strongly by outside communication with a powerful "electrical machine, but a gold-leaf electrometer within showed no effect. He says, 'I went into the cube and "'lived within it, using lighted candles, electrometers, and all other tests of electrical states. I could not "'find the least influence upon them, or indication of anything particular given by them, though at the time "'the outside of the cube was powerfully charged, and large sparks and brushes were darting off from every "'point of its outer surface.'"

The considerations which prevail to secure the rejection of the lightning theory are equally applicable in the case of a supposed "silent discharge." The suggested explanation may modify the difficulty to some slight extent, but it does not even approximately remove it.

If, on the other hand, by "silent discharge" is intended to be implied a discharge not between the clouds and the earth, but some mysterious electrical action or current within the earth itself ("terrestrial lightning" as it has been called), the explanation seems, if possible, more untenable. For, granting that "earth currents" do occur, and that not very much is known at present of these phenomena, it appears inconceivable that electricity under any circumstances or conditions should so far forget or set at defiance the laws of its nature as to forsake such an excellent conductor as the water through which it was peacefully flowing, to go into the bottom of a barge immersed in that water, and therefore protected by it as by the most effective lightning conductor,* and explode its contents.

I have examined the lightning and electricity theories more carefully than they perhaps appear to deserve, because the Company put forward as one of their pleas in defence of the action "Jackson v. Grand Junction Canal Company" that the explosion was caused by an agency of this sort. However, on the case coming on for trial, the lightning and earth current theories silently discharged themselves, and were not attempted to be sustained,—no doubt because on careful and honest investigation they were found to be ludicrously untenable.

(2.) With regard to the idea that sparks may have caused the explosion, it is evident that in order to support this view two propositions must be maintained: (*a*) that there were sparks; (*b*) that the sparks could reach the powder or some inflammable substance on board the boat. **Sparks.**

As to (*a*) I think it may be admitted that the presence of sparks may have been possible.

It scarcely appears possible that they could have come directly from the steamer, for the distance from the tug to the "Tilbury" could not have been less than from 70 to 80 yards,† and was probably nearly 100 yards.

At this distance it is very improbable that any sparks from the steamer could have fallen upon the "Tilbury." But it is not impossible that a spark from the steamer may have lodged in the interior of the bridge and the ignited particle, or some particle of soot or other inflammable accumulation ignited thereby might have become detached at the moment of the "Tilbury" approaching or passing under the bridge, or a spark may have flown from the cabin chimney of the "Dee" (the boat immediately in front of the "Tilbury"), and distant from it only about 10 to 20 yards, or a bargeman may have been smoking on the barge.‡

(*b*) But if we assume that from one or other of these causes, or from some other source, a spark reached the "Tilbury," it still becomes necessary to consider the probability of such a spark communicating with the contents.

Having examined several boats of this class, clothed in the manner already described (*see* p. 3), I must confess I find it exceedingly difficult to say in what manner a spark could reach the cargo. I will not go so far as to say that it is impossible, and there is one method of "clothing" the fore-end of the boats which does appear to afford a less perfect protection against external sources of danger than is afforded by what may be regarded as the normal mode.§

But the evidence went to show that the cloths used on board the "Tilbury" were good and nearly new, and, looking to the manner in which these cloths are lashed down

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* See note at p. 12 respecting electricity not affecting objects in the interior of a hollow conductor; and for the purposes of the present argument the water surrounding the barge may be regarded as such a hollow conductor.

† Taking the intervals between the boats at only 10 yards, there would be three such spaces, viz., between the tug and the "Jane," between the "Jane" and the "Dee," and between the "Dee" and the "Tilbury." Then the two boats "Jane" and "Dee" were each 70 feet long, making altogether nearly 80 yards. But it is probable that the interval between the boats averaged more nearly 15 than 10 yards. See p. 4.

‡ It was not disputed by the various witnesses that smoking took place on board the barges; indeed, there seems to have been no order against it, though it appears to have been forbidden at the wharf.

See the uncontradicted evidence of several witnesses as to this.

§ It was also stated in evidence that the tarpaulin sometimes fly open. (Thomas Boswell's evidence; proceedings, 12th October.) See also George Court's evidence, 12th October.

A witness in the trial at the Common Pleas also laboured to prove that the tarpaulin did not fit tight, and that therefore there would be ample ventilation from the interior,—a line of argument which suggests the obvious remark that if this were so, all the more blame attaches to the company for using an illegal boat without a close deck, and so imperfectly protected against external sources of danger.

and secured, I do distinctly consider that it would be a straining of probabilities to assume that the accident was caused by a spark finding its way into the cargo, even if we had no more reasonable explanation to set against this one.

It is of course not impossible, and at one time I was disposed to think it not improbable, that a spark from some source or another had communicated with and ignited some escaped petroleum vapour as it issued from the folds of the tarpaulin, and that the cargo thus became set on fire.

But although, as I believe I shall be able to show, the ignition of escaped petroleum vapour did without doubt cause this accident, I do not believe that the vapour became ignited by this agency, or under the circumstances above indicated. Briefly, I do not believe that the petroleum vapour became ignited by any source of fire *external* to the boat.

External ignition.

(3.) It has also been suggested (though not very strenuously) that the explosion was perhaps caused by a quantity of gas which had escaped from a gas-pipe in the vicinity and become ignited, which, as the boat passed by it, set fire to the boat. But this theory was I think hardly seriously put forward, although some evidence was given that there had been "an escape of gas for years on the right-hand side of the bridge."*

Moreover, there is the fact, which we may regard as established beyond dispute, that the accident originated (*i.e.*, the first burst of flame occurred) *before* the "Tilbury" reached the bridge, and could hardly therefore have been caused by a gas flame at the bridge.

And the acceptance of this theory would also apparently involve the conclusion that the "Jane" and the "Dee," both carrying powder, and one of them ("Dee") having petroleum in addition, had passed unscathed through or by the ignited gas flame, and none of the witnesses called from these boats appear to have noticed any appearance of any ignited gas.

Of course the explanation, even if it could be adopted, would only go to illustrate more strongly the imprudence involved in the illegal action of the Company in carrying gunpowder in a boat not having a close deck, and which could be so readily attacked by flame, and exploded in its passage.

This explanation would hardly have been worthy of notice if it had not been gravely referred to at the inquest.

Causes internal to the boat.

B.—*Causes internal to the Boat.*

These may be considered under the following heads:—

(1.) Heat from friction or percussion.
(2.) Spontaneous ignition.
(3.) Sparks.
(4.) Ignition of a match, percussion cap, detonator, or similar article.
(5.) Ignition by a fire or light.

Heat by friction or percussion.

As regards (1), although no provision whatever appears to have been made against such risks from undue friction as undoubtedly exist where a building, boat, or other vehicle containing gunpowder is treated as if it only contained ordinary merchandise, and grit and other hard foreign substances are allowed to be introduced in the process of loading, by the dirty boots of the men, or on the cases containing the goods, or from the boat having been used on some previous occasion for the carriage of goods themselves of a gritty character, and although in this particular instance it appears that a special element of risk of the sort was present in the shape of some sheets of sand or emery paper,† and although no special precautions in the mode of handling of the

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* Henry Coysh's evidence, 12th October.—This evidence, however, was at variance with that of George Court, the Park Inspector, who "passes over the bridge every day several times, and has not smelt any gas "nor yet heard any complaints as to gas."—12th October.

† Dr. Taylor's evidence, 20th October.

The extent of the danger of the explosion of gunpowder by friction or percussion is perhaps scarcely sufficiently appreciated.

The following extract from a small official pamphlet, entitled "Plain Hints and Directions for the Storage of Gunpowder, Guncotton, and other Explosives," prepared by order of the Home Secretary, will indicate the nature and reality of this risk, and will tend to correct the erroneous impression that a spark or some *visible* form of heat is necessary to produce the explosion of gunpowder. The fact is that gunpowder will explode at 560° Fahrenheit, other explosives at lower temperatures, whereas the lowest temperature at which heat becomes discernible is almost certainly not below about 800° Fahrenheit, and is probably nearer 1,000° Fahrenheit.

"Heat sufficient to fire gunpowder and other explosive substances may be produced by percussion or friction, without the presence of any spark or flame, or other *visible* indication of heat. This important fact is not

powder barrels and the loading of the boats appear to have been enjoined, it would, I think, be altogether unreasonable to assign the explosion to any such cause; for this cause could hardly be operative in a boat gliding quietly along a canal, when the cargo was undergoing no shifting or disturbance, and when, in fact, it is difficult to see how any friction could have been established.* The danger from friction or percussion is to be apprehended at the moment of loading or unloading, or stowing the cargo; but this explosion did not occur at such a moment, but at a time when it is almost certain that this class of risk was entirely latent.

Moreover, this explanation leaves unexplained the original bright burst of smokeless blue flame—whence derived and how produced.

(2.) *Spontaneous Ignition.*—It is quite certain that no spontaneous ignition of the gunpowder could have taken place, for it is perfectly well known that that explosive does not contain within itself the elements of such action. Spontaneous ignition.

It is therefore necessary to consider whether any of the other articles which were on board the "Tilbury" were of a nature liable to spontaneous ignition.

Now this cargo, according to the invoices which were handed in at the inquest,† consisted of gunpowder, petroleum, sugar, lead, vinegar, paper, wine, boards, cloths, drugs, coffee, nuts, and borax.

There is in this cargo nothing of a suspicious character so far as any liability to spontaneous ignition is concerned, and as no serious attempt has been made to account for the explosion on these grounds, though at one time it was understood that this was one of the lines of defence proposed to be adopted by the Company, it seems unnecessary to elaborate the consideration of this point.

(3.) *Ignition by Sparks.*—Here, again, very much the same observations as I have made with reference to the risks from friction apply; that is to say, the business of carrying gunpowder appears to have been carried on by the Grand Junction Canal Sparks from iron, &c.

sufficiently known or acted upon.* That it is a fact has been shown by several experiments, of which the following are examples:—

EXPERIMENTS WITH GUNPOWDER.

A 25-lb. weight was allowed to fall two feet upon small packages of gunpowder, consisting of about five grains of Government powder wrapped in tinfoil (so as to exclude the possibility of a spark reaching it).

The packages were placed between two metal plates and the blows struck as follows:—

Material of Plates.	No. of Blows.	No. of Explosions.
Both plates steel - - -	10	10
One plate steel, one plate brass -	10	4
Both plates brass - -	10	2
Both plates lead - - -	10	No explosion, even when the fall was increased to 40 feet.

In the official War Office *Treatise on Ammunition* (1874), pp. 8–9, the following results are recorded:—"Experiments carried out in the Chemical Department of the Royal Arsenal showed that a 50-lb. weight "falling 36 feet on a surface of one inch square, the surfaces being brass, having mealed powder $\frac{1}{20}$th inch "thick spread between them, exploded the gunpowder. The same weight falling on a surface of $\frac{1}{4}$ of a "square inch exploded the powder with a drop of 10 feet. This result coincides as nearly as possible with "what would be expected; having diminished the surface by $\frac{1}{4}$, we should have anticipated an explosion with "a fall of $\frac{1}{4}$ of that it previously required. In the foregoing experiment we should therefore have expected "it to explode with a fall of nine feet, while it actually required 10. The important fact to remember is "that the more we diminish the surface, the more readily will the powder explode; thus, if in the above "experiment we diminished the surface to the $\frac{1}{36}$th of a square inch, we should expect the weight to explode "it with a drop of one foot."

* "Too much stress cannot be laid upon the fact that gunpowder can be exploded either by a blow or by friction; this "forms a clue to most of the precautions which should be taken in dealing with it."—War Office *Treatise on Ammunition* (1874), p. 8.

From the foregoing the importance of excluding grit or hard foreign substances or hard surfaces from contact with gunpowder will be apparent.

"If any grit or sand is allowed to collect . . . . . the danger becomes great, as grit is harder than any metal, and the "sharp points coming into contact with powder dust would be just the most favourable conditions for an explosion."—*Treatise on Ammunition*, p. 9.

* It is of course possible that the boat coming into sharp contact with the bridge or the side of a lock might disturb the cargo somewhat and establish some friction, or throw down a barrel, but it would be straining a theory beyond endurance to assume, in the absence of strong corroborative evidence, that an explosion of gunpowder was likely to have been brought about in this way, while it should always be borne in mind that the accident certainly *originated* (*i.e.*, the first burst of fire was observed on board) *before* the "Tilbury" reached the bridge, and while she was moving quietly along the canal.

† See Appendix D. for invoices in detail of the cargoes of all the boats which were present on this occasion.

Company with a total disregard of even the most elementary precautions in regard to the avoidance of the risks of accident from sparks, struck out of iron or steel. The boats themselves were not specially fitted in any way, the nails and metal work were all of exposed iron, and the men engaged in loading the boats wore, while so engaged, their ordinary iron-nailed boots,* and the casks and cases containing the petroleum and other merchandise were iron-hooped and iron-nailed. But although, as I believe, this absence of precautions involved a very alarming risk at the points of loading or unloading, especially seeing that occasional leakage of the powder barrels is stated to have occurred,† and that, as I have already shown, grit was not excluded, so that practically each boat may be regarded to have been provided internally with a *flint and steel*; still this risk could scarcely have existed in an active form while the boat was travelling along the canal. And although I am of opinion that the Company are highly censurable for their reckless neglect or non-adoption of even the most elementary precautions in regard to the proper fitting of their powder boats, and the proper clothing of the men engaged in loading them,—a neglect which is the less excusable, seeing that the Company charged about 100 per cent. extra for the carriage of gunpowder, and some extra rate for the carriage of benzoline; and, although I consider that the public have been most improperly exposed to grave risk for years from the absence of these safeguards, I feel bound to express my opinion that this particular explosion cannot possibly be assigned to this cause; and again the observation occurs that this suggested explanation still leaves unexplained the origin and nature of the first silent burst of smokeless flame, unless, indeed, it is to be understood that some escaped petroleum vapour first became ignited in this way.

Lucifer matches, pipe-lights, &c.

(4.) *Ignition of a Match, Percussion Cap, Detonator, or similar Article.*—It does not appear from the invoice that any dangerous articles of this description were included among the cargo of the "Tilbury,"‡ and there are no special grounds for believing that any such articles were present in the stowage portion of the vessel. But, clearly, no special precautions were taken to prevent them from being present; that is to say, no steps were taken by searching the men engaged in loading the boats, or by requiring them to wear suits without pockets while so engaged, or by employing selected men only for duty in connexion with the loading of powder.§

Nor does it appear to have been the practice even to sweep or wash out a boat before powder was placed on board. So that it must be admitted that full opportunity was afforded for the presence of a stray match or pipe light, which had perhaps fallen from the pockets of the bargemen engaged in loading, or at some other time,‖ or which had

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* Evidence of Edward Hall, 7th October; of Mr. Hughes, same date, and others.

Indeed it was clear, from the fact that the men did not generally know when they had any powder on board, that no special precautions in the way of special magazine boots, &c., were taken with regard to the loading of it, and it is also clear that no attempt was made to cover up the ironwork in such boats as had gunpowder on board.

† Evidence of Edward Hall, 7th October.—Indeed, I have no hesitation in recording my conviction that such occasional leakage is unavoidable with the existing barrels commonly employed in the trade, subjected, as it appears they are liable to be, to almost as much rough handling about as a beer barrel.

‡ It may seem almost superfluous to establish that gunpowder and lucifer matches were not carried in the same cargo. I regret to say that my experience of the length to which imprudence will go in these matters, and the evidence of the length to which, as will presently appear, it did actually go in the present case, point to the necessity of leaving no direction or hypothesis unexplored simply on the ground that such direction or hypothesis assumes the commission of an act of egregious imprudence. And, as a matter of fact, I may mention that an experienced Thames powder lighterman recently gave me the particulars of a case which he himself witnessed, when 12½ tons of gunpowder were stowed on board an outward-bound ship on the top of a cargo of lucifer matches, without any intervening planks or merchandise.

The powder lighterman on expostulating was told to mind his own business.

§ I put to the witness Hall (captain of the "Limehouse") the following question:—"What precautions do you take to prevent the men from having matches in their pockets?" He answered, "*That is a point we "do not trouble about*" (7th October 1874). See also other evidence given by this witness, and evidence of Mr. Hughes (7th October), and Cherry (7th October).

In fact, I failed to discover in the course of my inquiry that any single, special, or extra precaution was enjoined with regard to gunpowder, and, as a matter of fact, the men often did not know they had gunpowder on board.

‖ Colonel (now Major-General) Boxer in his report on the Erith explosion of 1864 expressed his opinion that that accident was caused in this way. He says:—"I am inclined, however, to think that this accident "was not caused by sparks from fire on board the barge, but by the ignition of a lucifer match dropped by "one of the men who were engaged in unloading.

"I know from experience how impossible it is to prevent men carrying lucifer matches about their persons, "particularly when they are in the habit of smoking. Before I adopted the present plan of making all "persons employed in gunpowder work in the Arsenal change their ordinary clothes for suits specially "provided, before being allowed to enter the establishment, lucifer matches were occasionally found in the "buildings where gunpowder was used, and on the platform connecting them; and considering the stooping "position a workman must assume in unloading a barge, the escape of a match from the pocket is an "extremely probable event."

found its way forward accidentally from the cabin, where matches were used, or some dangerous article from a former cargo may have been left behind. But although the presence of a match or pipe light in the barge with the gunpowder was under the circumstances by no means impossible or improbable, a serious difficulty in the way of the acceptance of this explanation of the explosion presents itself in the fact which has already warranted the confident rejection of the friction and spark theories, viz., that however dangerous a match may be when lying among a cargo containing five tons of gunpowder and some casks of the most volatile description of petroleum, the danger would hardly assume an active form while the barge was quietly proceeding along the canal. The danger would become formidable at the time of handling the cargo,* but it would be a very remote danger indeed at any other time, and could hardly become a reality except through some shifting or disturbance of the cargo.

No doubt such shifting or disturbance *might* arise by the boat coming into collision with one of the piers of the bridge, or otherwise being subjected to some shock or concussion, as in passing through the locks; but here again it is to be noticed that the accident originated (*i.e.*, a fire of some sort certainly broke out on board) rather before the "Tilbury" reached the bridge, and while the boats were free of all locks, and not exposed, so far as one can judge, to any risk of concussion.

When I come to consider what I believe to have been the real cause of the accident, it will, I think, appear that to adopt the explanation which I am now discussing would be to adopt an exceedingly improbable, though not impossible, explanation, in preference to one which rests upon a footing of something more than probability.

Fire or light.

(5.) *Ignition by a Fire or Light.*—Here, I believe, we at last touch the true explanation of the accident. In order to establish this view it is necessary to show—

(*a.*) That a fire or light existed on board.

(*b.*) That it was possible or probable for the fire or light to communicate with the powder.

(*c.*) That the circumstances which are proved to have actually occurred were such as would have been likely to have occurred, assuming that the accident was caused in the manner now suggested.

If these propositions can be strongly established, and if, as I have shown, the various other explanations which suggest themselves have to be successively rejected as more or less impossible or improbable, it seems to follow as a necessary conclusion that the accident may be confidently assigned to the cause now under consideration.

As to the existence of a fire or light on board the "Tilbury."

As regards point (*a.*) the evidence establishes conclusively not only that fires and lights were not forbidden, and that they were habitually used on board the boats,† but that on this particular boat, on this particular morning, and within a few moments of the explosion, there was a fire burning brightly in the cabin. This last important point was spoken to at the inquest by police constable 162 S, Thomas Rodway, who deposed that he was on duty in the Albert Road, at St. Mark's Bridge, and was going off at 4.45 on the morning in question to Albany Street Station. He was on the bridge and saw five barges pass underneath, towed by a steam-tug. They were proceeding from the Camden Town Lock into the straight water. He saw smoke coming from the middle barge, and he saw some red-hot fire in the cabin.‡

The "middle barge" was the "Tilbury," and at the time at which this observation was made was a few minutes, probably from five to seven minutes, of the explosion. The credibility of this witness' statement was impugned by the counsel for the Company, on

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* See Note, page 16, as to Erith explosion having been considered by Colonel Boxer to have been caused by the ignition of a match; but in this case the accident occurred *while unloading was going on.*

† "There was a small fire in the grate of our boat" (the "Limehouse").—Edward Hall, 3rd October.

"In carrying gunpowder for Government from Weedon, for example, they have no fires. . . . . Under "other circumstances they have fires. The cabins are lighted with oil lamps."—(Edward Hall, 7th October.)

"There was no rule of the wharf against a fire on boats loading with gunpowder."—(Thomas Cherry, 7th October.)

John Edwards "had carried gunpowder before, and had had fires on board on those occasions. . . . . "They carry a lamp regularly. They could not see at that time of the morning without one. He had a fire "on board his boat the "Dee" that morning. He also had gunpowder."—(12th October.)

Thomas Boswell "had sometimes received orders not to have fires on board, but that was in a case of "Government powder. In other cases he had instructions to be very careful, but no order against fires. As "a matter of fact they do have fires on board when they carry powder. They had that morning. They had "a lamp, but no cotton, and they had used candles the last day or so. . . . . Mostly they burn colza "oil in their lamps."—(12th October.)

William White said he "never heard any order against having fires, and they had a fire that morning."—(19th October.)

‡ Evidence of 12th October 1874.

the ground mainly that he had made no report of the circumstance to his superior officers. But the statement has since been confirmed by the evidence of another police constable (S. 84, James Pritchett), who was examined at the Court of Common Pleas in the trial of "Jackson *v.* the Grand Junction Canal Company," and who deposed that he also saw the fire on board the cabin of the "Tilbury" at the time and place and under the circumstances specified by the witness above named.*

Moreover, as one of the witnesses† observed, a light of some sort was essential at that hour in the morning.

It may, therefore, I think be accepted as established beyond dispute that in accordance with custom the various boats composing this little fleet, and including the "Tilbury," had a fire or light, or both, in their respective cabins at the time when the explosion occurred.

Would a fire or light in the cabin of the "Tilbury" be likely to prove a source of danger to the cargo?

(*b.*) The next point for consideration is whether a fire or light in the cabin of this particular boat (the "Tilbury") could or would be likely to prove a source of danger to the cargo in that boat.

Now it is obvious that the mere existence of a fire or light in the cabin of a canal boat would not necessarily constitute a serious element of danger.

So long as the fire or light continued burning in the grate or lamp, without communicating with any surrounding objects, or setting the boat on fire, or emitting flame or sparks which could be carried into the cargo, no accident could arise. Unquestionably the having of a fire or light on board a vessel containing explosive substances is a grave imprudence, unless special precautions are adopted to prevent the possibility of any of the contingencies above intimated actually occurring. For example, the having of a fire on board a boat while it is being loaded or unloaded with gunpowder, or while the hatches are open,‡ is obviously unsafe, on account of the liability of the sparks from the chimney to be carried into contact with the gunpowder; and accordingly we find this practice forbidden by statute (23 & 24 Vict. c. 139. s. 22.), while the practice of having a fire on board a boat already loaded is not prohibited.§ But it must be obvious that the trade could not be carried on at all if there were a universal rule forbidding the having of any fire or light on board every ship or boat carrying explosives; and it must be conceded that such vessels may under particular arrangements have fires and lights with perfect safety. It is, therefore, necessary to resist the impression that the mere having of a fire or light on board a barge carrying gunpowder furnished *primâ facie* evidence of carelessness, or necessarily involved danger.‖

What was it, then, which made the presence of a fire or light in this particular instance a source of danger?

The answer to this question is—

That the danger consisted in a particular combination of circumstances of which the presence of the fire or light was one of the elements; and the substantial imprudence in this case consisted in the non-adoption of such precautions as would prevent such a combination arising under any conditions.

The combination to the existence of which this disaster may, as I believe, be confidently assigned was the following:—

1st. In addition to the gunpowder on board the "Tilbury," there were, as we have seen, four barrels of the most volatile description of petroleum, viz., "benzoline."

2nd. The bulkhead of the cabin was not hermetically or specially closed, but was provided with a small ventilating hole, which communicated from the cabin into the stowage portion of the vessel.

3rd. There was a fire and light in the cabin.

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* At the Common Pleas this point was, in fact, not disputed by the defendants. Pritchett was not cross-examined, and the other evidence on this point, which the counsel for the prosecution stated they could produce, was not thought necessary.

† Edwards.—(12th October.)

‡ It is a question whether, even assuming that powder could be lawfully carried in a boat without hatches (such as the "Tilbury"), it would be lawful at any time to have a fire on board such a boat since practically the hatches would always be open.

§ I do not desire to defend or explain the inconsistencies and omissions of this section, which allows a fire on board a boat laden with gunpowder, but forbids smoking on board; but there can, I think, be no doubt that the distinction drawn in this section between a boat of which the hatches are closed and one of which the hatches are open is a sound one; and it serves to illustrate the point upon which I am insisting, that the danger attending the having of a fire on board a gunpowder boat is variable according to circumstances.

‖ Fires at certain times and under certain conditions are recognised on board floating magazines. It need hardly be observed that all steam vessels conveying gunpowder necessarily have their engine fires on board throughout the voyage, and, indeed, no vessel, whether propelled by steam or otherwise, could perform a voyage of any duration without having both fires and lights on board.

We have here a set of conditions which, combined with the favouring condition of a well "clothed" and well filled boat, must sooner or later, as it will be easy to show, almost inevitably lead to a disaster.

Benzoline, as is well known, is the name given to one of a large group of the lightest and most volatile of the products of petroleum.* It is, in fact, substantially a *spirit*, and not an oil, and is obtained by subjecting crude petroleum to a process of refining and distillation.†

Benzoline gives off a highly inflammable vapour at natural temperatures (*i.e.*, at temperatures of about 50° or 60° Fahrenheit).‡

This vapour, as was stated by Mr. Keates, may be regarded as coal-gas, and when mixed in the proper proportion with atmospheric air the mixture is explosive.§

Assuming that some of the petroleum vapour was present in the "Tilbury," it would

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* Among these products are the substances known as "petroleum spirit," "naphtha," "benzine," "benzole," "benzoline," "gasoline," "Japanese spirit."

In America fanciful (and often misleading) names have been given to these oils when subjected to particular (but, it is stated, generally ineffectual) treatment for rendering them "non-explosive," such as "liquid gas," "aurora oil," "safety gas," "petroline," "puroline," "black diamond," "septoline," "anchor oil," "sunlight non-explosive burning fluid."—(Report of Board of Health, New York, 1870, p. 531.)

† Petroleum is the generic name applied by the "Petroleum Act of 1871" (34 & 35 Vict. c. 105.) to "any rock oil, Rangoon oil, Burmah oil, oil made from petroleum, coal, schist, shale, peat, or other bituminous "substance, and any products of petroleum, or any of the above-mentioned oils, which give off an inflammable "vapour at a temperature of less than 100° Fahrenheit." This definition often leads to a good deal of confusion, for the result is that the "petroleum" of commerce (*i.e.*, petroleum oil which does not give forth an inflammable vapour at less than 100°, such as the oils variously known as "petroleum oil," "rock oil," "paraffin oil," "coal oil," "astral oil," "crystal oil," "kerosine,") is not the same thing as the "petroleum" of the Act of Parliament, and one effect of this artificial distinction is, I cannot doubt, to foster a popular misconception as to the danger of the petroleum of commerce. In practice it is more convenient to designate the lighter oils (such as benzoline) "parliamentary petroleum."

‡ Dr. Alfred Swaine Taylor, F.R.S., stated in his evidence at the Common Pleas that it gave off vapour even at 32° Fahrenheit.

By the Petroleum Act, 1871, all benzoline (and other "parliamentary petroleum," see note, next above) is required to be labelled as follows:—"Dangerously inflammable." In the Act of 1868 the label was required to be follows:—"Great care must be taken in bringing any light near to the contents of this vessel, as "they give off an inflammable vapour at a temperature of less than 100° Fahrenheit."

The particular barrels of benzoline on board the "Tilbury" were labelled in accordance with the Act of 1871 with the words "Benzoline—highly inflammable." The consignment note contained a notice to the same effect.

§ A great deal of misapprehension exists with regard to this quality of benzoline, and petroleum generally. The material is very often spoken of as "*explosive*." As a matter of fact, it is not and cannot be explosive *per se*, for the reason that it is a hydro-carbon, without any oxygen in its composition. In order to burn or explode, the material or the vapour therefrom must be brought into admixture with oxygen, whether in the pure form or in the form of atmospheric air. Petroleum *per se* is no more capable of *explosion* than are the contents of a spirit vault, or of a coal cellar, or than is a stack of charcoal. All these substances are more or less readily *inflammable*, but they are not explosive. It is only when the vapour which the benzoline gives forth becomes mixed with the proper proportion of oxygen or air that it forms an explosive mixture, exactly as in the case of coal gas. The following extract from the evidence which I gave on this subject to the Parliamentary Committee of 1874 may be appropriately quoted here:—

"I do not consider that petroleum could properly be included in an Act of Parliament relating to explosive "substances; practically it is not an explosive substance at all. Petroleum *per se* is not explosive, but when "the vapour, which it gives off at different temperatures, according to the degree of volatility of the particular "petroleum, becomes mixed with a certain portion of the atmospheric air, then an explosive mixture is formed; "in short, petroleum is very much on the same footing in this respect as coal gas, which by itself is not "explosive, but which becomes so when combined with atmospheric air; it is merely an ingredient of an "explosive mixture. So petroleum is really not an explosive substance at all, and should no more find a place "in legislation relating to explosive substances than coal gas. I would also urge that if the fact that "explosions have been occasioned by the presence of petroleum be a reason for including it, the same "argument should prevail to secure the introduction of steam, or even compressed air, into the Bill; indeed, "we might push it further, and include flour mills, on the ground that explosions have occurred in "them.

"In the year 1872 one of the most destructive explosions that I ever saw occurred in a flour mill, killing 18 "or 19 people."—(Q. 203.)

The following passage from the writings of the late Dr. Arnott also bears upon this point:—Coal gas, "like the charcoal of gunpowder, is only one of the elements of a fulminating mass, and can no more "explode than the contents of a coal cellar can. Before it can burn at all, every particle or measure of it "must find somewhere, and mix perfectly with, two particles or measures of oxygen gas. A lighted taper "plunged into mere coal gas, instead of exploding the gas, is itself instantly extinguished by it."—(Arnott on the smokeless fire, &c., p. 212.)

Dr. Arnott states that one measure of gas to about 10 of air gives the strongest explosive mixture.

Captain Shaw, in a memorandum on gas explosions, gives the strongest mixture at one of gas to six of air; and he adds, that the smallest quantity of gas to be mixed with atmospheric air, in order to form an *explosive* mixture, is 9 per cent., or 1 vol. in 10, and the largest quantity is 20 per cent., or 1 vol. in 4.

Dr. A. S. Taylor (see p. 20, note) gives the proportion of petroleum vapour to air required to form an *explosive* mixture up from 1 in 8 to 1 in 14.

follow that this vapour, according to the proportions in which it became mixed with the air, would create a more or less inflammable or more or less explosive mixture.*

Assuming the volatilization of the benzoline in the "Tilbury" to proceed, it is obvious that the vapour would gradually and in increasing proportion pervade the whole of the space within which it was confined, and would, as opportunity offered, effect its escape by any openings which might present themselves. The movement of the travelling boat would of course be favourable to such diffusion of the vapour, and its more complete admixture with the air.

Briefly, therefore, assuming the generation of petroleum vapour within the "Tilbury," the ultimate result must be the more or less speedy and more or less certain formation of an inflammable or explosive atmosphere pervading the whole of that portion of the boat in which it was confined—the character of this atmosphere, and its degree of inflammability or explosiveness, varying with the rate at which the volatilization of the benzoline proceeded in relation to the air space within which it was established, and the rate of escape of the vapour from the boat.

As to probable accumulation of petroleum vapour in cabin of "Tilbury."

Before proceeding to demonstrate how the existence of such an atmosphere in a boat having a fire in the cabin, and an open ventilator between the cabin and the space so pervaded with the inflammable atmosphere, would necessarily constitute an active danger, it is advisable to consider the probability of the accumulation of the petroleum vapour within the "Tilbury."

Now, as to this point there is no room to doubt, not merely that such accumulation was probable, but that it would have been unreasonable to anticipate that the benzoline could have been carried without it arising to a greater or less extent. Several facts point to this conclusion.

1st. The fact that benzoline and the vapour therefrom will penetrate even well-made casks is well known to the trade, and appears to have been known even to the Grand Junction Canal Company, for, as a matter of fact, the consignment note which the Company required to be given with this description of merchandise contains these words: "The Grand Junction Canal Company not to be responsible in the event of any claim "being made by the consignees for deficiency of oil through leakage or evaporation." The note is also headed with words showing that it relates to a description of goods "giving off inflammable vapour at less than 100° Faht." (*See* Appendix E.)

2nd. So well recognised is this liability to leakage of the spirit or escape of its vapour, that special provision is made against it by coating the barrels internally with glue.

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* Mr. Keates informs me that he has found by experiment that one volume of benzoline vapour will render highly inflammable about 60 volumes of atmospheric air; and that one volume of benzoline vapour to 30 of atmospheric air is a violently explosive mixture. Mr. Keates, in a memorandum with which he has kindly furnished me, gives the following data:—

Benzoline, sp. gr. ·705. The cubic inch weighs 178 grains. A cubic inch of benzoline gives 142 cubic inches of vapour. The specific gravity of the vapour is 3·900. 100 cubic inches of the vapour weigh 125 grains. The vapour produced from a cubic inch of benzoline (= 142 cubic inches) requires more than 600 grains, or 1,700 cubic inches, of oxygen to burn it. This would represent five times as much atmospheric air; therefore one cubic inch of benzoline in the form of vapour (= 142 cubic inches of vapour) would require about 8,500 cubic inches, or about five cubic feet, of air to burn; consequently, one volume of benzoline vapour will render highly inflammable about 60 volumes of atmospheric air.

Mr. Keates deduces the further conclusion that 100 cubic feet of air would be rendered inflammable by about 18 or 20 cubic inches of benzoline converted into vapour, *i.e.*, a little over half a pint.

Or, the proposition may be stated thus, that a given volume of benzoline in the liquid form is capable of conversion into sufficient vapour to render inflammable 8,500 times the volume of atmospheric air; or, simply and roughly expressed, one cubic inch of the liquid when volatilized will render inflammable *five cubic feet of air*.

Dr. Alfred Swaine Taylor, F.R.S., has furnished me with some data of a similar character. He says: "A cubic inch of liquid benzoline (specific gravity, 708) at 60° weighs 154 grains, and is equivalent by measure to half an ounce, or one tablespoonful of liquid.

This small quantity of liquid is convertible into 116 cubic inches of vapour, having a specific gravity of nearly 4, as compared with air; when thoroughly mixed as vapour with 60 times its volume of air (116 + 6,960 = 7,076 cubic inches), and a lighted taper is applied, the mixture burns with a beautiful pale blue flame, and if the glass vessel containing the mixture is long and narrow there is rather a smart explosion at the end.

6,960 cubic inches of air are equivalent to 25 gallons, or about four cubic feet; one cubic inch of liquid in vapour will thus render combustible and inflammable about four cubic feet of air, or 25 gallons. This corresponds to a proportion of $\frac{1}{60}$th, *i.e.*, one of benzoline vapour to 60 of air. I have tried a proportion of one fortieth ($\frac{1}{40}$th) and the results were similar. If any liquid benzoline adhered to the jar in an unevaporated state it gave a yellowish colour to the flame.

One thirty-third ($\frac{1}{33}$rd) the same result.

One thirtieth ($\frac{1}{30}$th) the same result. In these last experiments the flame burnt of a reddish colour towards the end, *i.e.*, after the blue.

One twenty-second ($\frac{1}{22}$nd) a bluish flame, mixed sometimes with red.

One fourteenth ($\frac{1}{14}$th) burnt with a yellowish flame, slightly explosive towards the end.

The application of a lighted taper to proportions thoroughly mixed with air, in which the vapour was from $\frac{1}{8}$th to $\frac{1}{12}$th, would be dangerous."

But even if we assume that the coating is in all cases originally complete and effective, it is quite clear that the ordinary concussions of transport,* and any variation in form which the barrels may undergo from vicissitudes of climate, must tend to break this internal skin of glue, and to destroy the protection which it is designed to afford. In fact, at best this expedient can be but a palliative.

But obviously the coating is not likely to be invariably uniformly applied in the first instance, while it is well known in the trade that the barrels are themselves not unfrequently defective. There is also the chance of escape from the bung hole,—a contingency which is so well recognised that it was an instruction on the part of the Grand Junction Canal Company to their men to stow the petroleum barrels "bung up."†

And the practice sometimes followed of making the bung tight with a piece of cloth or canvas driven in by the cork appears to me likely to establish another source of leakage, viz., leakage by capillary attraction. Then, also the remarkable readiness with which wood is capable of absorbing oil must be reckoned among the active sources of escape of the spirit and vapour.‡

3rd. That from these various sources, and notwithstanding the glue lining, loss of benzoline by leakage and evaporation does take place to a very serious extent is admitted by the trade. Thus, Mr. Barringer, the consignor of the particular benzoline which was on board the "Tilbury," said, in reply to a question which I put at the inquest, "Do "you recognise in the trade an appreciable loss from leakage and evaporation"? "Well, "it certainly forms an item in our profits."§

In the course of my communications with the trade, and quite irrespective of this inquiry, I have found that loss by leakage and evaporation is always recognised as more or less inevitable, and the following information given to me by Mr. Shotter, the manager of the Petroleum stores of the London Wharfing and Warehousing Company, at Plaistow,—the largest stores, I believe in the kingdom, and where the average stock is about 58,000 barrels, is very interesting.‖

Mr. Shotter said that with petroleum oil (*i.e.*, non-"parliamentary petroleum") the average leakage may be taken at about three gallons per (36 gallons) barrel per year, equal over 8 %. With petroleum spirit the loss is much greater, as it proceeds by evaporation as well as by leakage through the wood, and Mr. Shotter considers that it may be taken as an average at about six gallons per (36 gallons) barrel per year, equal over 16 %. Mr. Shotter had known it mount as high as 10 gallons per barrel. It should be stated that this loss has been observed to occur in well-ventilated stores, where special contrivances, such as jets of water, are adopted for keeping down the temperature, which I am assured never rises therein above 62° Fahrenheit.

4th. It is of course not to be supposed that petroleum carried by the Grand Junction Canal Company enjoys any special immunity from the loss by leakage and evaporation to which other petroleum, as appears from the above, is exposed. But as illustrating, somewhat strikingly, the actual but unobserved existence of a leaky petroleum barrel on the Company's wharf, which barrel appears to have gone forward in one of their boats in the ordinary course of business, I would relate the following circumstance. On the 6th October 1874, I went to the wharf of the Grand Junction Canal Company, at City Basin, and asked if they had any benzoline or petroleum of any sort on the wharf, as I desired to examine the cask. I was shown a cask of benzoline, the only one there. It was standing on its end, prior to being put into the boat. The bung was covered

* The extent to which the figure and tightness of a barrel are liable to be disturbed by concussion is sufficiently evidenced by the fact that it is a common practice to remove the bungs by what is called "flogging" them out, *i.e.*, striking the staves around the bung until the latter flies out.

† It is perhaps superfluous to observe that, although this precaution would no doubt tend to prevent *leakage* of the spirit itself at the bung, it would certainly not contribute to prevent evaporation through whatever openings might exist at the bung; while the fact that this practice is adopted points unmistakeably to the conclusion that a certain want of tightness in the bungs is recognised in the trade. Further, if a cask having a defective bung were allowed to stand on its end before being put into the boat, leakage would become established and vapour would continue to be given off after it was embarked. (See text, as to the leaky barrel on the wharf.)

‡ Some interesting experiments on this point were made in the Royal Laboratory in 1865.

The results are so curious that I thought it might be useful to place them on record. (See Appendix F.)

It will be observed that a single barrel stave (presenting 144 superficial inches to penetration) absorbed of linseed oil in 24 hours amounts varying from $\frac{3}{16}$ ozs. to $\frac{54}{16}$ ozs. Not the least remarkable feature about these experiments is the unexpectedly large absorbing power of such hard woods as box and elm.

§ 12th October 1874.—Mr. Barringer repeated this evidence in substance at the Common Pleas.

‖ This information was given to me when I was engaged in officially inspecting these stores on the 13th December 1874, and when it certainly was not Mr. Shotter's interest to make the loss by leakage or evaporation appear greater than it actually is.

with a tin patch. I observed it closely, and noticed a gradual "weeping" or leakage therefrom.*

I called the attention of one of the officials of the Company to this leakage. He disputed its being leakage, and said the barrel had been standing in some mud.

I wiped it off with my finger, and satisfied myself by the smell that it was petroleum. I also observed and called the clerk's attention to the fact that the place so wiped almost immediately became wet again. In about half a minute enough leaked out to thickly coat my finger.

The leakage in this case was therefore a very rapid leakage. That it was actually a leakage of benzoline, I satisfied myself by the following means. I procured a little piece of sponge and a stoppered bottle, and tearing the sponge into small pieces, saturated the pieces successively with the oozing spirit, and introduced them into the stoppered bottle, which I took home with me. The following morning on taking up my bottle I found that it was broken, and I feared that my labour had been lost.

However, finding that a piece of the sponge was very inflammable, I placed the pieces into another bottle, and took it up to Mr. Keates' laboratory. In his presence I removed the stopper, applied a light to the mouth of the bottle, and obtained a small explosion, with blue flame. Here, then, we have evidence that an amount of leakage of petroleum spirit, which I do not hesitate to say was really considerable, may not only pass unobserved, but its existence may actually be denied even when attention is expressly called to it, and the appearance may be assigned to some other cause.†

These considerations, I think, sufficiently establish the character of benzoline, its extreme volatility, inflammability, and the liability to escape, whether of the spirit or its vapour, which always exists in a greater or less degree when the material is packed in wooden casks.

It is clear I think from the above that, assuming the existence of wooden casks of benzoline in a more or less closely confined space at a temperature at which volatilization can take place, the atmosphere will gradually but surely become impregnated with the benzoline vapour, until in time (if sufficient ventilation be not provided) it becomes inflammable and afterwards explosive, according to the proportions in which the air and vapour are mixed.‡

Therefore this condition of things must have arisen sooner or later on board the "Tilbury."§

Of course, if we assume leakage, it might arise very rapidly. But even taking the normal evaporation of benzoline, as already stated, viz., about six gallons per 36 gallons (or over 16 °/₀) per annum, we should have an evaporation on the four casks of about half a pint in 24 hours. If the temperature were high, this evaporation (which is the average during all the seasons of the year, taking hot and cold weather together) would of course proceed more rapidly, and the night in question was close and hot. Therefore, even taking the normal loss from benzoline casks, we should have during the eight hours that elapsed between the clothing up of the "Tilbury" and the explosion‖ a very appreciable evaporation.

It is obviously impossible to say with any precision what amount of evaporation would suffice to render the atmosphere under the tarpaulins of the "Tilbury" inflammable unless we know what was the amount of air space left by the cargo. But from the evidence which was given at the trial at the Common Pleas as to the close packing of

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* See note, p. 21, ante, as to the insufficiency of the precaution of placing the barrels "bung up" on board the boats.

† It is worthy of remark that this cask appears to have been sent away in the same state in which I saw it, *i.e.*, "weeping" freely, on the following day in the boat "Highbury," together with a consignment of gunpowder. (See evidence of John Walker, 19th October 1874.)

‡ See pp. 19, 20.

§ I do not overlook the evidence which was tendered at the trial at the Common Pleas, as to the tarpaulins not fitting very tightly, and so allowing the escape of the vapour; but the cross-examination of the witness showed that if the tarpaulins did not fit tightly they necessarily failed to fulfil the very object with which they are employed, and with which they are so carefully laid on, overlapped, corded down, and secured; and it was distinctly stated at the inquest that the tarpaulins of the "Tilbury" were "thoroughly good; in fact nearly new."—(Evidence of Thomas Cherry 7th October 1874.) Indeed, up to the time when the importance of the ventilation theory came to be perceived by the Company, as bearing upon the suggestion that the explosion had been caused by the formation of an inflammable atmosphere by the accumulated vapour under the tarpaulin, great stress was laid upon the perfect fitting and the excellence of the tarpaulins, which it was implied were just as secure as the close deck required by the Gunpowder Act. The suggestion that the tarpaulins were not close fitting was not, that I am aware of, made until the trial in the Common Pleas. See p. 13, note.

‖ The "Tilbury" was clothed up about 9 p.m. on the 1st October (see evidence of Thomas Cherry 7th October), and the explosion occurred about 5 a.m., 2nd October 1874.

the cargo, and from the models which were then produced and sworn to as representing with sufficient accuracy the mode of stowage of the cargo, it is quite clear that the air space must have been very small indeed; and Mr. Keates' experiments have shown that about half a pint of benzoline will furnish sufficient vapour to render imflammable no less a space than 100 cubic feet of air.* I am therefore decidedly of opinion that it is by no means necessary to establish the existence of any exceptional leakage or escape from the casks of benzoline on board the "Tilbury" to account for the formation of an inflammable atmosphere under the tarpaulins during the eight hours which preceded the explosion. At the same time I consider that it is exceedingly probable that such exceptional leakage had taken place, a probability which is enhanced by the circumstances—

1st. That two of the barrels of benzoline had been standing on the wharf exposed to all the hazards of blows and concussion for over a fortnight.†

2nd. That, as described by one of the Company's witnesses,‡ the barrels were put on board by being rolled along over the rough stones with which the wharf is paved.

No doubt it was stated in evidence that the barrels as delivered by Mr. Barringer and as put on board were sound and good, but it is worthy of notice that they were not put on board until after dusk, and when there was no artificial light;§ further that, as I have already shown,‖ the officials of this Company were quite capable of neglecting to observe or failing to detect, even when their attention was expressly directed to it, a considerable leak in a benzoline cask; and, finally, there is no one to speak as to the blows and concussion which one or more of the barrels may have received *after* they had been put on board or while being embarked, for the simple reason that the only men who could so speak were killed by the explosion.

While, therefore, I do not think it necessary to establish that the barrels actually leaked, in order to account for the formation of an inflammable atmosphere under the tarpaulins, I am decidedly of opinion that the balance of probability is in favour of there having been such leakage. But that such an atmosphere was formed, whether with or without leakage, I have no doubt.

Manner in which inflammable atmosphere could become ignited.

The next stage in this argument is the consideration of the manner in which the inflammable atmosphere thus formed became ignited.

Of course numerous ways might be suggested, such as one or other of the ways by which it has been suggested the powder itself may have become ignited; but there is one explanation so much more probable than the others, and which so exactly fits with what was actually observed to occur, that it may, I think, be unhesitatingly accepted.

This explanation is that the mixture of benzoline vapour and air found its way through the bulkhead into the cabin and coming into contact with the fire, which we know was burning there, took fire. The ignition thus established would at once pass back through the interstices or apertures in the bulkhead, and communicating with the inflammable portions of the cargo, would ultimately cause the explosion of the gunpowder.

It still remains to be considered whether there is any proof, or a reasonable presumption, that any sufficient means of communication through the bulkhead existed.

On this point it is admitted that there is in the bulkhead of all boats of this sort a hole, which is sometimes lozenge shaped, sometimes round, and which in the "Tilbury" it is believed was about three inches in diameter. This hole serves two purposes: (*a*) to enable persons to look through when the boat is empty and to observe anyone on board; (*b*) to serve as a ventilation to the cabin.

The hole can be closed at will by means of a sliding shutter. There is no direct proof that the hole was open on the night in question; indeed it was argued on behalf of the Company that the sugar bags which were stowed in this part of the vessel would really close the hole, and that there would accordingly be no occasion for keeping it open. But, obviously, this argument admits of a more reasonable application in the other direction. If there was no reason why the hole should have been open, what reason, it may be asked, was there that it should be closed? The only object of closing the hole would be to diminish excessive ventilation; but if the stowage of the cargo was such that the ventilation through the hole could not be inconvenient or excessive, there would be no object in closing the slide. And, as a matter of fact, seeing that it was a close, hot

* See p. 20, note.

† Viz., from the 14th October, on which date they had been delivered to the Company by Messrs. Barringer, the consignors.

‡ Thomas Cherry (evidence of 7th October 1874).

§ Evidence of Thomas Cherry, 7th October 1874.

‖ See pp. 21, 22.

night, the desire of the boatmen, if they had any desire upon the subject, would rather be to keep the hole as much open as possible, and that in proportion as the stowage of the cargo artificially diminished the current of air. So that I think the probabilities are decidedly in favour of the hole having been open and not closed.*

Moreover, even if we assume the hole to have been closed, it is quite clear that it was not hermetically closed. The mere sliding forward of the little shutter would certainly not prevent the passage of air, though it would diminish the volume liable so to pass. We may therefore, I think, take it that, whether the hole were closed or opened, there was not that complete closing which could prevent the passage of benzoline vapour and air through this portion of the bulkhead, such passage being necessarily favoured by the draught established towards the cabin, (*a*) by the forward movement of the boat, (*b*) by the fire in the cabin.

And it may further be added, that my examination of several bulkheads in boats of this class leads me to the belief that, quite independent of the hole and its shutter, the division between the cabin and the cargo is very far from being strictly air-tight.†

A good deal of stress was laid at the trial upon the close packing of the cargo, and the obstacle which this would oppose to the passage of the vapour and air. But this argument is really not worth anything, unless it can be pushed to the length of establishing an absolute hermetical closing of the after-part of the boat.

Short of this, the argument only amounts to this: that because of the close stowing of the cargo there was so much less air space for the benzoline vapour to disperse through, and therefore a less amount of such vapour would suffice to render the atmosphere in that space inflammable. Of course it would not have been possible to establish an hermetical closing of the after-part of the vessel by means of a cargo composed partly of bags of sugar and partly of sugar loaves. The latter, however stowed, would inevitably offer a number of approximately cylindrical channels for the passage of air, while the bags could hardly pack so closely together that no air could go through them.

Assuming, therefore, the existence of an inflammable mixture of benzoline vapour and atmospheric air, there was nothing to prevent the passage of that mixture into the cabin. Indeed, such passage would under the circumstances be inevitable; and when the mixture reached the cabin it would in process of time be liable to come into contact with the fire or light, and so become ignited.

That this would really happen I have been able to demonstrate experimentally in a manner which is sufficiently convincing. In arranging and carrying out my experiments I received invaluable assistance and advice from Professor Abel. The details of the various experiments which I have made bearing upon this subject are given in Appendix G. They may be briefly said to have consisted of experiments designed to show by successive developments—1st. The inflammability of a mixture of benzoline vapour and air. 2nd. That such a mixture may be ignited at a distance from the source of supply of the vapour, and when ignited will act as a carrier of flame back to the source of supply. 3rd. The rapidity with which such a vapour will form even in an imperfectly closed vessel. 4th. That in a comparatively short time the mixture issuing from a hole in the closed vessel produces an inflammable atmosphere in the neighbourhood of that hole.

The first of these points is easily illustrated by applying a light to the vapour given off by benzoline. The second point may be illustrated by pouring some benzoline into a tall glass, and after a short lapse of time applying a light to the top of the glass, when the mixture ignites briskly and burns down the glass with a quiet smokeless blue flame. (*See* Experiments, series B., Appendix G.)

The third point I illustrated by evaporating some benzoline in a wooden box with an ill-fitting lid, and applying a light to the interior, when a brisk ignition, scarcely to be distinguished from a slight explosion, was generally obtained. (*See* Experiments, series B., Appendix G.)

The last point I illustrated, in the first place, by applying the light to the outside of the box (*See* series B., Appendix G.), and, more effectively, by applying it in the cabin of a

* I may mention that I personally visited a large number of canal boats similar to the "Tilbury," loaded and unloaded, and I do not recollect finding the hole in the bulkhead closed on board one of these boats.

† This was denied by one of the witnesses at the trial at the Common Pleas, and he expressed his belief that the bulkhead was accurately air-tight. He, however, admitted that the bulkhead was introduced *after* the vessel was built; and it is certainly a fact that in some of the boats which I examined the bulkhead was very flimsy and defective. It is at any rate certain that petroleum vapour did habitually escape into or make itself sensible in the cabins, because the witness Hall stated that it was always possible to know by the smell when benzoline was on board.

John Bennett also gave evidence to the same effect. (These men were both witnesses called by the Company.)

little model of the "Tilbury." (*See* series C., Appendix G.) In both cases I generally obtained an ignition or explosion, which communicated with the vapour in the interior of the barge or box.

I was able to exhibit the experiment with the barge successfully at the coroner's inquest, putting in half an ounce of the same description of benzoline as was on board the "Tilbury,"* and applying a lighted taper in the cabin at the end of ten minutes. In some of my trials, it will be observed, I exploded small quantities of gunpowder and guncotton in the barge in this way.

It may therefore be accepted that, given a formation of benzoline vapour, under the tarpaulins of the "Tilbury," the natural course of events would be exactly that which I have endeavoured to describe, viz., the gradual formation of an inflammable mixture, the percolation of that mixture through the bulkhead into the cabin, its ignition by the fire which was present in the cabin, and the communication of the flame to the inflammable atmosphere in the body of the boat, resulting in the ultimate explosion of the gunpowder.†

Coincidence of probable and actual appearances.

(*c.*) This, then, being the natural course of events, it must materially influence the acceptance of this explanation of the accident if we find that the actual observed occurrences did exactly coincide with what under the supposed circumstances would almost certainly have happened. Assuming that the accident did occur in the manner suggested, what might an observer have been expected to see?

1st. He would probably observe, in the first instance, a quick burst of silent smokeless blue flame, the ignition of the inflammable atmosphere.

2nd. This would probably be succeeded by a few moments, or it might even be minutes, of apparent extinction of the flame, as the flame passed under the tarpaulins and there attacked the cargo.

3rd. Finally, there would come the explosion, when the fire thus established in the interior of the boat reached the gunpowder.

Now this is precisely what did occur.

In order to show this it is only necessary to recal the conclusions established in the first part of this Report,‡ which conclusions it may be useful at this point to repeat.

1st. "That the main explosion on board the 'Tilbury' was preceded at a brief interval "(probably something under a minute) by a sort of preliminary puff or "muffled explosion, accompanied by a vivid burst of blue flame without "smoke, from the cabin of the 'Tilbury.'§

2nd. (*a.*) "That this burst of flame was sufficiently remarkable and alarming to call "forth strong comments from both the steerer of the 'Tilbury' and the "steerer of the 'Dee,' and to lead to the steamer being stopped because "the 'Tilbury' was believed to be on fire.

(*b.*) "That the apprehensions thus momentarily excited were almost immediately "allayed by the instantaneous disappearance of the exciting cause, and "that the sudden flash was succeeded by a few moments of stillness, during "which the steamer again went ahead.

3rd. "That almost directly after the steamer had again begun to steam ahead the "five tons of gunpowder on board the 'Tilbury' exploded."

If the appearances which might naturally be expected to result from an occurrence of the nature supposed and the actual appearances as established by the evidence of eye-witnesses were printed, side by side, in parallel columns, it would be seen that it would be scarcely possible to have a more accurate coincidence of circumstances. I may here state, also, that I first obtained the clue as to the probable cause of the accident from the very precise and positive statements, in hospital, of the witness White as to the previous outburst from the cabin of the smokeless blue flame, and the succeeding interval of darkness between the flash and the explosion.

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* The benzoline for this experiment was obtained from Messrs. Barringer, the consignors, who informed me that it was precisely the same as that on board the "Tilbury."

† As to the exact manner in which the gunpowder became ignited it is difficult to express an opinion.

It is of course possible that the disturbance caused by the first ignition of the vapour caused injury to one of the barrels, and so exposed some of the powder, but I think it is far more probable that the powder barrels remained intact until the flame from some portion of the burning cargo, whether the petroleum, the benzoline, the sugar, or other goods, found its way through the joints of one or more barrels and exploded the contents.

Under any circumstances there would almost necessarily be an interval of time before the explosion.

‡ *See* pp. 6, 7.

§ It has been remarked that some of the witnesses spoke to a blue flame, and others to a red flame. But the experiments made by Dr. A. S. Taylor (*see* p. 20, note) show that both these effects might have been produced by the ignition of a mixture of petroleum vapour with air, according to the proportions in which the vapour mixed in the atmosphere, and it is of course possible that an observer may have noticed a flash from one

We thus have, 1st, a chain of occurrences exactly coinciding with the occurrences which would naturally have been expected if the accident had arisen from the cause suggested; 2nd. We find that no other explanation which can be suggested goes at all near fitting the case or agrees with the established sequence of events; 3rd. We have all the elements present for producing the accident in the particular manner here supposed.

Conclusion as to cause of explosion.

I may now claim, I think, to have satisfactorily established the propositions which I laid down as necessary to support the explanation now suggested. This being the case, I venture to say that it is impossible, without resisting the most obvious and legitimate inference, and wantonly preferring an improbable explanation to one which really proceeds as a natural consequence from the established facts, for anyone who brings a candid and intelligent judgment to bear upon this matter, to come to any other conclusion than that the explosion was certainly caused by the ignition of an inflammable mixture of petroleum-vapour and air which had found its way into the cabin of the "Tilbury," and come into contact with the fire there existing, and which carried back the flame into the body of the boat, where it shortly exploded the gunpowder.

It is satisfactory to me to be able to record that this explanation has been accepted without hesitation by two juries.

The coroner's jury found that "the explosion was caused by the ignition of the vapour "of benzoline by a fire or light in the cabin of the 'Tilbury,' and that the Grand "Junction Canal Company were guilty of gross negligence in omitting proper pre-"cautions in the transport and stowage of the cargo."* And a special London jury in the Common Pleas gave a verdict for the plaintiff in the case of "Jackson *v.* the Grand Junction Canal Company" on both the counts of creating a dangerous nuisance and of negligence, the particular negligence consisting in the carrying of benzoline and gunpowder together, and the having a fire in the cabin of the boat.†

Professor Abel, who is one of the most eminent of living authorities on the subject of explosives, in a lecture which he delivered at the Royal Institution on the 12th March 1875, on "Accidental Explosions," made the following observations upon the cause of this explosion:—

"It is scarcely to be realized that the indifference with which gunpowder has been "treated by those who undertake its transport by water could have attained such an "extreme, that powder packages could be stored in the hold of a barge, side by side "with casks of petroleum spirit, by persons whose experience must have made them "cognizant of the liability to leakage of petroleum from such casks.

"Such leakage (occasioned perhaps by rough handling in placing it on board) must "inevitably furnish in course of time an explosive atmosphere by the diffusion of "inflammable vapour through the air confined in the barge hold (which is closely covered "in); the extension of this explosive mixture to the small opening which these barges "contain in the bulkhead separating the hold from the small cabin, or its penetration "through crevices in the bulkhead, is but an affair of time, and then, whichever of the "several sources of fire provided on board the barge, *i.e.*, the stove, lamp, or lucifer "matches, happens to come within reach of the quick-match which the explosive atmo-"sphere constitutes, completes the arrangement for inflaming any small quantity of "petroleum which may have leaked out, or in close proximity to a powder barrel.

"But for the fact that a concurrence of several conditions is essential to the communi-"cation of fire to gunpowder, through the agency of a leakage from a petroleum cask in "a confined space, it can scarcely be doubted that the rude awakening which the public "recently received to the danger they were frequently exposed to in the vicinity of "canals where powder traffic goes on, must have occurred long since. The simple flash "produced by a mixture of hydro-carbon vapour and air would probably not suffice to "ignite powder grains exposed to it, but any small quantity of the liquid itself which, "leaking from a cask, has furnished the vapour, may be in close proximity to a few grains "of loose powder, or upon a powder barrel which is not securely closed, or some other "simple conditions resulting in the conveyance of the fire to the powder may be fulfilled, "and then explosion must ensue."‡

It is not unimportant as bearing upon the above explanation of the cause of this explosion to state that a very similar disaster occurred on the Thames so recently as the 30th June 1873.

In this case, however, there was fortunately no gunpowder on board, only mineral oils and spirits. But the circumstances attending the loss of the "Maria Lee" are in

* Verdict of 19th October 1874.

† Verdict of 14th May 1875.

‡ "Accidental Explosions," pp. 37, 38.

their main features sufficiently analogous to those which led to the destruction of the "Tilbury" to merit a few words of notice before passing away from this branch of the subject. The "Maria Lee," bound for Plymouth, was proceeding down the Thames with a cargo of 200 barrels of naphtha, 119 barrels of petroleum, and 13 barrels of linseed oil, and some pitch. She had loaded at Plaistow Wharf, and had arrived in Long Reach. It is the practice of vessels carrying these volatile oils and spirits to keep their hatches open for ventilation, but owing to a severe thunderstorm on the preceding evening the captain had ordered the hatches to be covered with tarpaulins. This was between 8 and 9 p.m. At 10 minutes past 5 on the following morning (30th June), on the captain entering the cabin at the after-end of the vessel, a loud explosion occurred, the force of which is stated to have showed itself forward, instantly followed by a flame. The vessel's head was put away from the direction of the Purfleet Gunpowder Magazine which she was approaching, and she was abandoned by the captain and crew, some of them being much burnt and bruised. The vessel burnt for some hours, and was totally destroyed.

It was proved that some of the petroleum on board was of a highly volatile description, precisely similar in this respect to the petroleum on board the "Tilbury," and it was in wooden casks, which were stated to have been good, though some "weepings" at the bung holes had been observed. The tarpaulins, as already stated, had been over the hatches for almost exactly the same period as in the case of the "Tilbury," viz., from about 9 p.m. till 5 a.m., and during this period there can be no doubt that the vapour had accumulated to a considerable extent.

The exact cause of the ignition was never ascertained, for it was positively asserted that there was neither fire nor light on board, but it was suggested that a spark had been struck by the captain from the iron-fronted cabin stairs as he descended them, though a more probable explanation is that he accidentally trod upon and ignited a lucifer match.

At any rate, there is an interesting parallelism in the two cases, and it might have been supposed that this affair, which was very fully reported in the newspapers and excited a good deal of attention at the time, and which can hardly fail to have come under the notice of the carrying trade, would have suggested to the Grand Junction Canal Company the expediency of forbidding the carriage of volatile mineral oils and spirits in the same boats with gunpowder.*

In short, looking to the fact, as disclosed by the Company's consignment note (*see* Appendix E.), that they were thoroughly alive to the nature of benzoline and to its liability to evaporate; looking to the fact that a vapour which would penetrate through a wooden cask might certainly be expected to make its way through a bulkhead with a 3-inch hole in it, or even through a bulkhead without any such hole, if not made absolutely and strictly close in every joint and part; looking to the fact, also, that the inflammability of the vapour given off by petroleum and the explosibility of gunpowder are matters of common knowledge, and, finally, looking to the emphatic testimony borne by the destruction of the "Maria Lee" (and other vessels) to the hazardous character of a cargo of petroleum; looking, I say, to these various considerations, I must profess my amazement that the merest commercial prudence did not suggest to the Company the propriety of separating the benzoline and gunpowder in transit, or, at any rate, forbidding by the very strictest regulations any lights or fires on board boats so laden.

It must also be a matter for surprise that an explosion of this sort did not occur long ago. Indeed, it is difficult to say which of these two circumstances—the hazardous mode of conducting their gunpowder traffic which the Company adopted, or the long immunity from disaster which they enjoyed—is most calculated to excite astonishment.

4. *General Remarks.*

General remarks.

This disastrous explosion appears to suggest a few general remarks.

It will I think be clear from what has been stated that the carriage of gunpowder has been carried on by the Grand Junction Canal Company with a degree of carelessness, and with a neglect of the most elementary precautions which can hardly fail to amaze even those who have some familiarity with the recklessness which too often prevails in regard to explosives.

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* It is not a little remarkable that the explosion of the "Lottie Sleigh," at Liverpool on the 9th January 1864, was caused by the ignition of some mineral oil (in this case paraffin) which escaped from a can which a steward was using to refill a lamp, became ignited, and flowed in a burning stream through the grating of the lazarette into the cargo, where, after the lapse of 1 hour and 20 minutes, it reached and exploded the powder.

I have shown that, as a matter of fact, no difference whatever was made by the Company in the carriage of gunpowder and of other goods, except the difference in the rate, which in the case of gunpowder was about 100 per cent. in excess of the ordinary rate. This fact renders it the more remarkable, and, I must add, the more inexcusable, that no increased or adequate precautions should have been enforced with a view to minimizing the dangers incidental to the carriage of a material the dangerous character of which the Company's charges showed emphatically was thoroughly appreciated.

But, in fact, no single special precaution appears to have been taken in the gunpowder traffic. The loading and unloading was, so far as I have been able to discover, carried on in exactly the same way, under exactly the same conditions, and in the same places as the loading of any other merchandise. There was, it is true, a magazine attached to the wharf at the City Basin, but the construction and arrangement of this magazine appear to have been such that it can hardly be regarded as having materially contributed to the diminution of risk from accidents, while the practice of storing gunpowder at all on a busy wharf is one which calls, I think, for decided condemnation. The plan usually adopted by the railways of not receiving any powder except when it can be *at once* despatched is one which ought to be followed in these cases.*

The boats were not in any way prepared for the reception of the powder, either by the extinction of fires, by the covering up of the exposed iron, by the laying down of cloths; nor were they such boats as are required by law, nor were the men engaged in the loading required to wear proper shoes and clothing. A consignment of gunpowder, as has been shown, was stowed away indifferently with other goods, including that particular description of merchandise (benzoline) which the Company's consignment note proves they knew gave off an inflammable vapour 100° Fahrenheit, and for which, on account of its dangerous character, they charged an extra rate; and, notwithstanding the presence of the gunpowder, benzoline, and other goods of a highly inflammable description, fires were permitted on board, and smoking (except, I understand, at the loading wharf itself) does not appear to have been forbidden. But although this neglect of precautions is in the highest degree censurable, I am afraid it cannot be considered altogether exceptional, and in my "Report on the necessity for the Amendment of the Law relating to Gunpowder, &c.," and in my evidence before the Parliamentary Committee on Explosive Substances, in the Session of 1874, I called particular attention to the grave dangers to which the public were exposed from the prevailing carelessness in the matters of the carriage of explosives, and from the absence of sufficient controlling power over the persons engaged in this traffic.

That these dangers are grave, and that the existing statutory regulations and powers on this subject are inadequate, will, I think, appear from the following facts:—

(1.) Notwithstanding a statement in a letter addressed to my late assistant (Captain Smith) on the 2nd February 1872, that the quantities of gunpowder carried by the Grand Junction Canal Company "are usually small," it appears from the evidence which was forthcoming at the inquest, that the amount of gunpowder transported by the Company has for some years been very large, and, from a return handed in by the traffic manager, I find that during the three months preceding the explosion no less than 267 tons of gunpowder was carried by the Company in consignments varying from 11 tons downwards (*see* Appendix H.);

(2.) That during this period there were only eight working days† on which at least one boat, and frequently more, was not despatched with a mixed cargo of gunpowder and petroleum;

(3.) That the traffic manager distinctly stated at the inquest that he did not see how any material alteration could be made in the manner of carrying on the gunpowder traffic;‡ and that, as appeared in the course of the proceedings instituted against Messrs. Mellor, Colsell, and Company in October 1874, similar laxity has prevailed in the case of at least one other canal company;

(4.) That the gunpowder carried by the canal companies is very far from being the only gunpowder carried in large quantities through London, as appears from a return at

* From a letter dated 2nd February 1872, written by the traffic manager of the Grand Junction Canal Company, to my late assistant, Captain Smith, I was under the impression that the powder was never allowed to remain upon the wharf. In this letter it is stated "the gunpowder is sent forward on the same day that "we receive it, and is put into the boat last thing before the boat leaves the wharf. If the boat is not ready "to start when the powder is brought in the senders' vans, it is put into a magazine provided for the purpose "until the boat is ready to receive it." It is, however, clear from the evidence given by Mr. Hughes before the Coroner (7th October 1874), that this regulation was by no means invariably observed.

† 21st and 23rd July; 13th, 22nd, and 23rd August; 12th, 17th, and 18th September.

‡ Mr. Hughes' evidence of 7th October.

pp. 284, 285, and 286 of the Report of the Select Committee on Explosive Substances, which shows that the quantities so carried and shipped at Blackwall Stairs alone* (there being other shipments at Wapping, Collier Dock, Blackwall, and Bow Creek) were as follows:—

In	Tons.	
1870	241	In consignments varying from 22 tons downwards.
1871	75	
1872	132	
1873	122	

The quantities carried by the railways also, and loaded or unloaded at their goods stations, is very large, while the regulations adopted by the railways are certainly in some cases inadequate to provide against accident;

(5.) That the powder so carried is practically subjected to scarcely any statutory restrictions,—at any rate it is not subjected to adequate restrictions; while such restrictions as are imposed cannot be enforced owing to the absence of any sufficient powers of entry or inspection of wharfs, boats, or vehicles.†

Sooner or later these evils must have made themselves manifest; and it must be a subject for congratulation that the full extent of the risk to which the public was exposed by the existing defective legislative provisions for controlling this traffic was so forcibly brought to notice, at a cost, so far as human life was concerned, which may be regarded as comparatively inconsiderable.

There can be no doubt that London and other large towns have been for years exposed to the risk of a catastrophe rivalling some of the tremendous explosions which are recorded in history, such as the explosion at Leyden in 1807, and at Eisenach in 1810.‡ Measured by possible consequences, it must be admitted that we have bought our experience in this matter cheaply.

The explosion must also be regarded as having occurred at a favourable conjuncture, seeing that it did not come wholly as a surprise, but after a Session in which the whole question of legislation regarding explosives had been carefully investigated, and when an amending statute on the subject was in course of preparation. Thus, instead of having the disastrous effect, which is one of the evils to be apprehended from any great public catastrophe of this sort, of producing hasty and panic legislation,§ the explosion really served rather the useful function of stimulating and giving point to the exertions of

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* Blackwall Stairs is a public landing-place, and the shipment of powder is carried on with people standing all about, some of them smoking, and with an entire absence of those precautions which are necessary to reduce the risk of accidents to a minimum.

† The coroner's jury appended to their verdict an expression of opinion that "the existing statutory laws "are inadequate to secure the public safety." The Parliamentary Committee also reported that "the law "relating to the . . . . . carriage . . . . . of all substances of an explosive nature does not "make adequate provision for the safety of the public, or of the persons employed in such . . . . . "carriage . . . . . and that further legislation is urgently required."

As inspector under the Gunpowder Act I have no power of entry into or inspection of a place where powder is stored in transitu only (*see* Biggs v. Mitchell, 31 L.J. M.C., 163), and even if I had it is quite clear that no system of central inspection could cope effectively with so large a mischief.

Search warrants can of course be obtained when there are good grounds for suspecting an illegality (*see* 23 & 24 Vict. c. 139, sec. 23), but independently of the fact that some magistrates require a strictness of proof before granting a search warrant little short of what would be necessary to secure a conviction, there is the further consideration that a search warrant is a singularly clumsy and inconvenient instrument in the case of goods in transitu and a *moving* illegality.

‡ Both these explosions were caused by powder in transitu. At Leyden a gunpowder barge laden in the canal blew up; the loss of life and property was tremendous.

At Eisenach the explosion is believed to have been caused by a spark struck by the iron-shod hoofs of the horses drawing some powder waggons through the streets. The loss of life on this occasion was very great.

§ Indications of the tendency on the part of the public to rush to extremes have not been wanting on the present occasion. There was at first a very decided, and perhaps under the circumstances not unnatural, disposition to cry out for the absolute prohibition of the carriage of gunpowder through towns, a prohibition which must virtually have had the effect of strangling the trade, and of materially injuring the numerous industries, especially mining, which depend upon gunpowder for their operations.

Since the explosion, also, a large number of projects for getting rid of gunpowder magazines from particular localities, some of them without any justification on the score of public safety, and framed without the slightest regard to the necessities or interests of trade, have been submitted.

One of these schemes would have involved the compulsory closing (apparently without compensation) of more than half the store gunpowder magazines in the kingdom, and it was seriously propounded and backed up by a very large number of persons.

A more useful effect of the explosion has been the impetus thereby given to inventions having for their object the safe packing and carrying of explosives. Some of these are no doubt put forward on ridiculous grounds, as in the case of a proposition which reached this Department, that the nails in bargemen's boots should be made of copper, not only because iron nails might cause an explosion (which of course is sound), but because "they would attract lightning." But some of the schemes which have come under my notice are certainly of a hopeful character, and under the more elastic provisions of the Explosive Substances Act of the present Session may perhaps ultimately be brought into useful operation.

those who were at the time engaged in the elaboration of a new Bill, and of assisting the passage of the Bill through Parliament. It is to be hoped that the Explosive Substances Act of 1875 will afford the public all the protection which can reasonably be expected, while duly regarding the interests of trade. Under this Act certain regulations will be laid down for the carriage of explosives; canal and other carrying companies will be required to make byelaws for the safe carriage of these goods over their navigation, or railroads, and the safe loading or unloading of the same, which byelaws will have to be approved by the Board of Trade; while facilities for local inspection and observation are provided, coupled with increased powers to the Government Inspectors.

The Act will not come into operation until 1st January 1876, but meanwhile the attention which has been directed to this subject has had a beneficial effect upon the carrying companies, who have, so far as my knowledge goes, adopted increased precautions and taken some steps towards the introduction of a safer system. In the case of the Grand Junction Canal Company some close-decked boats, with suitable internal fittings, have already been provided for the carriage of gunpowder, which is now carried on by them from Brentford only, so as to avoid the transit through London, and I understand that the sending of mixed and dangerous cargoes is now avoided.

Messrs. Mellor, Colseil, and Company have not, I believe, resumed the carriage of gunpowder since the proceedings were instituted against them in October last.

The railway companies have also subjected their rules to revision.

I am very far from saying that what has been done affords the full measure of protection which the public have a right to demand; on the contrary; much will have to be accomplished before the gunpowder traffic of this country is established on a safe or satisfactory footing. But there can be no doubt that one immediate effect of the Regent's Park explosion has been to diminish the very grave risk to which persons living in London and some other large towns have for a long period been unwittingly exposed, and another result has been to facilitate the introduction of the more stringent measures of protection and precaution which an improved law alone can furnish, and which this explosion shows had been too long postponed.

It is also in one sense a matter of satisfaction to know that this explosion would certainly not have occurred had even the simplest and most elementary precautions been observed by the Grand Junction Canal Company, even the simple precaution which the Regent's Canal Company had informed this Department they enforced on their navigation, of forbidding fires and lights on board;* for while it furnishes a justification for the more stringent legislation with regard to the carriage of explosives which the interests of public safety imperatively demand, it points to the conclusion that there is a class of so-called "accidents" which will be avoided under proper regulations, and which therefore if the new Act be carefully worked will be eliminated from the list of risks and casualties to which the public are exposed.

I may state that I have purposely postponed rendering this Report until after the trial of the action (Jackson *v.* Grand Junction Canal Company) against the Company in the Common Pleas, for the double reason that I was anxious to avail myself of any additional evidence which might be forthcoming at that trial, and because I thought it might be fairer to the Company to withhold the Report while the case was *sub judice*.

I have, &c.

V. D. MAJENDIE,
Major, R.A.,
Her Majesty's Inspector of Gunpowder Works.

The Right Honourable
The Secretary of State,
Home Department,
Whitehall, S.W.

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* *See* p. 2, extract from letter from Regent's Canal Company of 8th February 1872.