Royal Institution of Great Britain.

WEEKLY EVENING MEETING,

Friday, March 6, 1857.

Sir Charles Fellows, Vice-President, in the Chair.

Edmund Beckett Denison, M.A. Esq. Q.C. M.R.I.

On the Great Bell of Westminster.

I wish it to be understood that I have nothing that can be called a scientific theory of bell-founding to propound. I do not even profess to give the reasons why any particular form of bell is better than others; nor have I been able to find any one, among the best mathematicians of my acquaintance, who knows how to deal with the question mathematically. I have no doubt that the long-established form of church bells was arrived at gradually by successive deviations from some much simpler form, such as the hemispherical, or hemispheroidal, or conical; especially as bells of these forms, and of uniform thickness, always strike every body at first as very superior to the common bell, by reason of their having a deeper and more imposing tone at a short distance.

Neither have I anything to say of the history of bells. The only part of their history that I am concerned with is, that in old times people knew how to make bells of a full, rich, and sweet sound; and that the art of making such bells has been sinking lower and lower, until we have seen no less than three peals in succession made by two of the only three makers of large bells in England for the Royal Exchange, and the chimes not yet allowed to play, because a perfect peal has not yet been produced. At the same time, it must not be supposed that all old bells are superior to all modern ones. It would be difficult to find a worse bell of any age than Great Tom of Oxford, which was cast nearly two centuries ago, and might be recast into a more powerful bell, with the weight so much reduced as to pay its own expenses; and I have seen much smaller bells of the same age as the Oxford bell, as unsoundly cast as the second peal at the Exchange, in which some of the bells were full of holes, distinctly visible on the surface.

And further, I wish to observe that we have nothing to do at present with any question of musical notes, inasmuch as the subject is not the making of a peal of bells, which must of course be in tune with each other, but a single bell, which would have answered its purpose just as well with any other note as the E natural, which it happens to sound. I do not mean to say that it was not ascertainable beforehand that it would be of this note, as soon as the shape, size, and thickness were determined; and it is very convenient that it should be some note exactly, according to the pitch now accepted among musicians, because a bell is the most permanent of all musical instruments; and so long as this bell lives there will be no room for dispute about what was the accepted musical standard in England in the middle of the nineteenth century, assuming some record to be kept that this bell was then E natural exactly. But the problem we had to solve in making this first and largest of the five clock bells was, not to produce a bell of any given note, but to make the best bell that can be made of the given weight of 14 tons, which had been fixed long ago as the intended weight. When I say the best bell that can be made, I mean a combination of the most powerful and most pleasing sound that can be got—not, observe, the deepest; for we could get any depth of note we liked out of the given weight, by merely making the bell thinner, larger, and worse, as I shall explain further presently.

All that I have to do, therefore, is to describe the observations and experiments which led me to adopt the particular form and composition which have been used for this the largest bell that has ever been cast in England. The result is, undoubtedly, a bell which gives a sound of a different quality and strength from any of the other great bells in England. Of course it is very easy to say, as some persons have said, that we have got a clapper so much larger than usual, in proportion to the bell, that the sound must needs be different. But the reply to that is equally easy: the bellfounders always make the clapper at their own discretion; and in order to make the most they can of their bells, you may be sure they will make the clapper either as large as they dare, with regard to the strength of the bell, or as large as they find it of any use to make it; because there is always a limit, beyond which you can get no more sound of a bell by increasing the clapper. In the Westminster bell we found that we could go on increasing the sound by increasing the clapper up to 13 cwt., or say 12 cwt., excluding the shank or handle of the clapper, or about $\frac{1}{27}$th of the weight of the bell; which is somewhat higher than the proportion found to hold in some of the great Continental bells; but two or three times as high as the usual English proportion. And if the makers of the other large bells in England have found it either useless or unsafe to put clappers into them of more than $\frac{1}{60}$th, $\frac{1}{80}$th, or $\frac{1}{100}$th of their weight, it certainly is not surprising that the sound of this bell should be so different from theirs, as it is observed to be. The truth is, that the difference in the size of the clapper is the consequence of the bell having a much greater power both of bearing blows and of giving out sound than usual; and if we knew nothing more about the matter than that there is one large bell in England which will advantageously bear a clapper twice as heavy in proportion as any other, it would be enough to show that there must be some essential difference between the constitution of that and other bells, which is worth investigating.

The art of bellfounding having sunk so low, as is indicated by what has taken place at the Royal Exchange, and by the great bell of York being not used at all, after having cost £2000, except having the hour struck upon it *by hand* once a-day, it was obviously necessary to begin at the beginning, as we may say, and take nothing for granted as proper to be adopted, merely because we find it in common use now. Accordingly, when I undertook the responsibility of determining the size, and shape, and composition of these five bells, the bellfounders having refused to take any responsibility beyond that of sound casting according to orders, the Chief Commissioner of Works authorised the making of such experiments as might be required before finally determining the design and composition of the bells. Those experiments have only cost about £100, a small sum compared with the value of this one bell, and quite insignificant compared with the importance of success or failure in a national work of this kind. I may observe also, that there is no reason to believe that the art of making large bells is at present in a more flourishing state abroad than here. All the foreign bells in the Great Exhibition of 1851 were bad. Sir Charles Barry and Professor Wheatstone were requested by the Board of Works to make inquiries on the subject at the Paris Exhibition in 1855; and it appears that there is no foreign bellfounder who has cast any bell above a quarter of the weight of the Westminster bell; and the proportions of copper and tin which were stated to be used by the one who has the highest reputation, M. Hildebrand, of Paris, differ from those which I am satisfied are the best, both from the analysis of old bells of great celebrity and from my own experiments. I am equally convinced, that the French shape of bells is not only not the best, but is not so good as what may be regarded as the standard English shape.

I have said already that you may get any depth of note out of a bell of any weight by making it thin enough. At first, everybody who hears a bell, like that which stood at the west end of the Exhibition of 1851, sounding with 29 cwt. very nearly the same note as our 16 ton bell, is ready to pronounce the common form of bell, with a *sound bow* of $\frac{1}{12}$th or $\frac{1}{15}$th of its diameter, a very absurd waste of metal. But did it ever occur to them to consider, how far they could hear that 29 cwt. hemispherical bell? It could not be heard as far as a common bell of 2 or 3 cwt.; and before you get to any great distance from a bell of that kind, the sound becomes thin and poor, and what we call in bell-founding language, potty.

Up to 7 or 8 inches, these bells do very well for house clocks, to be heard at a little distance; but nothing, in my opinion, can be worse than the bells of this shape, 2 or 3 feet in diameter, which people seem to be so fond of buying for the new fashioned cemeteries: whether from ignorance that they will sound very differently on the top of a chapel and in the bellfounder's shop, or because they think a melancholy and unpleasant sound appropriate, or because they want to buy their noise as cheap as possible, I do not pretend to say. These bells, and thin bells of any shape, bear the same kind of relation to thick ones, as the spiral striking wires of the American clocks bear to the common hemispherical clock bells; *i.e.* they have a deeper but a weaker sound, and, are only fit to be heard very near. A gong is another instrument in which a deep note, and a very loud noise at a small distance, may be got with a small weight of metal; but it is quite unfit for a clock to strike upon, not merely from the character of its sound, but because it can only be roused into full vibration by an accumulation of soft blows. Gongs are made of malleable bell-metal, about 4 of copper to 1 of tin, which is malleable when cooled suddenly.

The Chinese bells, some of which are very large, may be considered the next approximation towards the established form; for they are (speaking roughly) a prolate hemispheroid, but with the lip thickened; whereby the sound is made higher in pitch but stronger, and better adapted for sounding at a distance when struck with a heavy enough hammer. But still the shape of the Chinese bells is very bad for producing sound of a pleasing quality; and generally it may be said, at least I have thought so ever since I began bell-ringing twenty-four years ago, that all bells of which the slant side is not hollowed out considerably, are deficient in musical tone. The Chinese bells are not concave but convex in the slant side. None of the European bells are so bad as that; but all the French bells that I have seen, or seen pictures of, and the great bell of St. Peter's at Rome, of which a model is exhibited, are straighter in the side than ours. According to my observation, no bell is likely to be a good one unless you could put a stick as thick as $\frac{1}{12}$th of the diameter between the side or *waist* of the bell and a straight edge laid against the top and the bottom. There was a very marked difference between two of our experimental bells, which were alike in all other respects, except that one was straighter in the waist than the other, and that was decidedly the worst. This condition is generally satisfied by the English bells: indeed I think the fault of their shape is rather the contrary, and that they open out the mouth too much, as if the bell had been jumped down on a great anvil while it was soft, and so the mouth spread suddenly outwards. The shape which we adopted, after various experiments in both directions, is something between the shape of the great bell of Notre Dame, at Paris, (of which a figured section was sent over last year by the present architect of the Cathedral,) and that of the great bell of Bow, which is probably much the same as that of St. Paul's, York, and Lincoln, as they all came from the same foundry in Whitechapel. Indeed, the sound-bow of this bell is fuller outside than the Paris bell, because it is thicker; so much so, that a straight edge laid externally against the top of the bell and the sound-bow would be thrown out beyond the lip; whereas generally such a straight line would touch the lip, and just clear the sound-bow. Only within the last few days I have found one other remarkable exception to this general rule of construction, and a remarkable coincidence with the external shape, and the proportions of height, breadth, and thickness of our bell, and that is no other than the great bell of Moscow, of which an exact section is given in Lyall's Russia, with various different versions of its weight. The inside shape, however, is not the same, and I am satisfied not so good, the curve being discontinuous, and presenting an angle just below where the clapper strikes, as in the Paris bell. That bell seems to have had a very short life, a large piece having been broken out in a fire the year after it was cast. Sir Roderick Murchison tells me that the sound of the Russian bells is remarkably sweet.

I cannot find that the exact height of a bell makes much difference. The foreign bells, except the Russian ones, it seems, are generally higher than ours, being nearly $\frac{5}{6}$th of their diameter high, whether you measure it vertically inside, or obliquely outside from the lip to the top corner, as the two measures are generally much alike on account of the curvature of the top or *crown*. Ours run from $\frac{2}{3}$rd to $\frac{3}{4}$th of the diameter, though there are some higher; and on the whole my impression is against the high ones. The vertical height inside of all these bells at Westminster is $\frac{17}{24}$ of the diameter. Lower than that, the bell does not look well; and I never saw an ugly bell that was a good one; and it is clear from all our experiments, that the upper or nearly cylindrical part is of considerable importance, and though its vibrations are hardly sensible, it cannot even be reduced in thickness without injury to the sound, of which we had a curious proof. A bell of the usual proportions, in which the thickness of the upper or thin part is one-third of the *sound bow* or thickest part, sounds a third or a fourth above the proper note when it is struck in the waist, and the sound there is generally harsh and unmusical besides. It occurred to both my colleague, the Rev. W. Taylor, and myself, that it would be better to make the waist thinner, so as to give the same note as the sound bow. After two or three trials we succeeded in doing this very nearly, and without reducing the waist below $\frac{1}{4}$th instead of $\frac{1}{3}$rd of the sound bow. The bell sounded very freely with a light blow, and kept the sound a long time, and a blow on the waist gave a much better sound than usual. But for all that, when we tried it at a distance with another bell of the same size and same thickness of sound bow, but a thicker waist, the thin one was manifestly the worst, and had a peculiar unsteadiness of tone, and sounded more of what they call the harmonics along with the fundamental note, instead of less, as we expected.

But still we have to ascertain what should be the thickness of the sound-bow itself (which is often called for shortness the thickness of the bell). The large bells of a peal are sometimes made as thin as $\frac{1}{16}$th of the diameter, and by one of the modern bellfounders even thinner, and the small ones as thick as $\frac{1}{10}$th of the diameter. It is clear that the most effective proportion is from $\frac{D}{12}$ to $\frac{D}{13}$. In casting peals of bells it is necessary to take rather a wider range, in order to prevent the treble being so small and weak as to be overpowered by the tenor; though here I am convinced that the modern bellfounders run into the opposite error, and always make their large bells too thin. I know several peals in London in which the large bells are hardly heard when they are all rung, and are besides very inferior in quality to the others. Again, if you make the small bells too thick, for the purpose of getting a larger bell to sound the proper note, you approach the state in which the bell is a lump of metal too thick to have any musical vibration. This is a much less common fault than the other, because the nearly universal demand for as deep notes as can be got for the money is a strong temptation to make the thickest bells, *i.e.* the small ones, only just thick enough, and the large ones much too thin. Nothing can be more absurd than to spend from £300 to £800 on a peal of bells, which are merely got for the purpose of giving pleasure to those who hear them, and then insisting on their being made in a key which they cannot reach without being thin and bad and disagreeable. People evidently fancy they are getting more for their money by getting bells in a low key than a high one, whereas they are really getting less, inasmuch as they only get the same quantity of metal and have it spent in producing a bad article instead of a good one. The tenor of the new (third) peal at the Exchange is only 33 cwt., and sounds the same note, C, as that of Bow Church, which weighs 53 cwt. It is very evident that one of them must be wrong: you need only go and hear one strike eleven and the other twelve, and you will not have much doubt which it is. It is true that the tenor of the previous (second) peal at the Exchange, though still worse, was of the same weight, and as the founders alleged in their own defence, from the same patterns as Bow; but the bells must have been of bad metal, and some of them were certainly bad castings. The thickness of the Westminster bell was designed to be $\frac{2}{25}$th of the diameter, or 9 inches, which would have made it 14 tons, the weight which was prescribed for it twelve or thirteen years ago, long before I had anything to do with the bells or the clock. By some mistake in setting out the pattern, or making the mould, which the founders have never been able to account for, the bell was made $9\frac{3}{8}$ inches thick, which is very nearly $\frac{1}{12}$th of the diameter, 9 ft. $5\frac{1}{2}$ in., and which increased the weight to

16 tons, within 174 lbs., and raised the note from E flat to E. Fortunately the same ratio of increase was made throughout, and the waist is $3\frac{1}{8}$ in., or one-third of the sound-bow, as it ought to be; and therefore the only effect of the mistake is, that the bell is heavier and more powerful; for it being cast the first, the alteration of the note did not signify, as the four quarter bells can as easily be made to accord with E natural as with E flat. And as they will be rather smaller in consequence, the aggregate weight of the whole five will be about 24 tons, as I originally estimated. I have only to add, with reference to this part of the subject, that the width of the bell at the top inside is half the width at the mouth, as it generally is; though in some bells, for instance, the great clock bell at Exeter, it is the outside diameter that is made half the diameter at the mouth. It is of no use to state here the precise geometrical rules by which the pattern of a bell of what we now call the Westminster pattern is drawn, as they are purely empirical. I mean, that having got a bell, by trial, which we all agreed was better than any other, I made out some sufficiently simple rules for drawing the figure of its section by means of a few circles whose radii are all some definite numbers of 24th parts of the diameter of the bell: but there is no kind of *a priori* reason, that I know of, why a bell whose section or *sweep* is made of those particular curves, should be better than any other; and therefore I call the rules for tracing the curve merely empirical; and as they would be of no use to any one but bellfounders, who know them already, or easily may, if they like, I shall say no more on this part of the subject.

As I have been asked many questions about the mode of calculating the size of a bell, so as to produce a particular note, and the answer is very simple, I may as well give it, though it may be found already, with other information on this subject, in the only English book I know of which contains such information, I mean the second edition of my *Lectures on Church Building*, to which a chapter on bells is added. If you make eight bells, of any shape and material, provided they are all of the same, and their sections exactly similar figures (in the mathematical sense of the word), they will sound the eight notes of the diatonic scale, if all their dimensions are in these proportions—60, $53\frac{1}{3}$, 48, 45, 40, 36, 32, 30; which are merely convenient figures for representing, with only one fraction, the inverse proportions of the times of vibration belonging to the eight notes of the scale. And so, if you want to make a bell, a fifth above a given one—for instance, the B bell to our E, it must be $\frac{2}{3}$rd of the size in every dimension, unless you mean to vary the proportion of thickness to diameter; for the same rule then no longer holds, as a thinner bell will give the same note with a less diameter. The reason is, that, according to the general law of vibrating plates or springs, the time of vibration of similar bells varies as $\frac{\text{thickness}}{(\text{diameter})^2}$. When the bells are also completely similar solids, the thickness itself varies as the diameter, and then the time of vibration may be said simply to vary inversely as the diameter. But for a recent letter in the *Times* from a Doctor of Music, who seems to have taken this bell under his special protection, it would have seemed superfluous to add that the size of the "column of air contained within a bell" has no more to do with its note, than the quantity of air in an American clock has to do with the note of the wire on which it strikes. You may have half a dozen bells of different notes, because of different thicknesses, all enclosing exactly the same body of air. I certainly agree with the opinion published by some of the bellfounders on a former occasion, that musicians are by no means necessarily the best judges of bells, except as to the single point of their being in tune with each other.

The weights of bells of similar figures of course vary as the cubes of their diameters, and may be nearly enough represented by these numbers—216, 152, 110, 91, 64, 46, 33, 27. But as we are now only concerned with the making of a single bell, I shall say no more on this point, beyond desiring you to remember that the exact tune of a set of bells, as they come out of the moulds, is quite a secondary consideration to their tone or quality of sound, because the notes can be altered a little either way by cutting, but the quality of the tone will remain the same for ever; except that it gets louder for the first two or three years that the bell is used, probably from the particles arranging themselves more completely in a crystalline order under the hammering, as is well known to take place even in wrought iron.

We may now consider the composition of bell-metal. It is so well known to consist generally of from 5 to 3 of copper to 1 of tin, that all the alloys of that kind are technically called bell-metal, whatever purpose they may be used for; just as the softer alloys of 8 or 10 to 1 are called gun-metal; and the harder and more brittle alloy of 2 to 1 is called speculum-metal. But you may wish to know whether it has been clearly ascertained that there is no other metal or alloy which would answer better, or equally well and cheaper. The only ones that have been suggested are aluminium, either pure or alloyed with copper; cast steel, the iron and tin alloy, called union-metal; and perhaps we may add, glass. The first is, of course, out of the question at present, as it is about 50 times as dear as copper, even reckoning by bulk, and much more by weight. I have not heard any large steel bells myself, but I have met with scarcely anybody who has, and does not condemn them as harsh and disagreeable, and having in fact nothing to recommend them except their cheapness; and as I said before, nothing can be more absurd than to spend money in buying cheap and bad luxuries. Much the same may be said of the iron and tin alloy, called union metal, of which there was a large bell in the Exhibition of 1851. It was said by Mr. Stirling, the patentee of that manufacture (though I understand the same alloy is described by Rinmann, in 1784), that it did not answer to make bells of it with the sound-bow thicker than the waist, as usual; and if such bells are worse than the thin ones of that composition, I can only say they must be very bad indeed. I have seen also some cheap bells, evidently composed chiefly of iron, but I do not know what else, and they are much worse than the union metal bells. It is hardly necessary to say much of glass, because its brittleness is enough to disqualify it for use in bells; but besides that, the sound is very weak, compared with a bell-metal bell of the same size, or even the same weight, and of course much smaller.

There is another metal, which you will probably expect me to notice as a desirable ingredient in bells, that is silver. All that I have to say of it is, that it is a purely poetical and not a chemical ingredient of any known bell-metal; and that there is no foundation whatever for the vulgar notion that it was used in old bells, nor the least reason to believe that it would do any good. I happened to hear of an instance where it had been tried by a gentleman who had put his own silver into the pot at the bellfoundry, some years ago. I wrote to him to inquire about it, and he could not say that he remembered any particular effect. This seemed to me quite enough to settle that question. You may easily see for yourselves that a silver cup makes a rather worse bell than a cast-iron saucepan.

Dr. Percy, who has taken great interest in this subject, has cast several other small bells, by way of trying the effect of different alloys, besides the iron and tin just now mentioned. Here is one of iron 95, and antimony 5. The effect is not very different from that of iron and tin of the same proportions, and clearly not so good as copper and tin; and I should mention that antimony is generally considered to produce an analogous effect to tin in alloys, but always to the detriment of the metal in point of tenacity and strength. Again, here is a bell of a very singular composition, copper 88·65, and phosphorus 11·35. It makes a very hard compound, and capable of a fine polish, but more brittle than bell-metal, and inferior in sound even to the iron alloys. Copper 90·14, and aluminium 9·86, which makes the aluminium bear about the same proportion in bulk as the tin usually does, seemed much more promising. The alloy exceeds any bell-metal in strength and toughness, and polishes like gold; and as was mentioned in the lecture here on aluminium last year, it is superior to everything except gold and platinum in its resistance to the tarnishing effects of the air. This alloy would probably be an excellent material for watch wheels, the reeds of organ pipes, and a multitude of other things for which brass is now used—a far weaker and more easily corroded metal, but as yet much cheaper. But for all this, it will not stand for a moment against the old copper and tin alloy for bells; in fact, it is clearly the worst of all that we have yet tried. Here is also a brass model for casting bells, which is of course a brass bell itself, and that is better than the phosphorus and aluminium alloys, though inferior to bell-metal. (These were all exhibited.)

So much for the compound metals that have been tried as a substitute for bell-metal. But we have now, through the kindness of M. Ste. Claire Deville, of Paris, who exhibited the mode of making aluminium here last year, the opportunity of realizing the anticipation then formed, from the sonorousness of a bar of aluminium hung by a string, and struck. He has taken great pains in casting a bell of this metal, from a drawing of our Westminster bell, reduced to six inches diameter. He has also turned the surface, which improves the sound of small bells, where the small unevennesses of casting bear a sensible proportion to the thickness of the metal, and in fact, has done everything to produce as perfect an aluminium bell as possible, though at its present price it can hardly be regarded as more than a curiosity. But now for the great question of its sound. I am afraid [ringing it] that it must be pronounced to exceed all the others in badness, as much as it does in cost. I cannot say I am much surprised; indeed you may see in the book I have referred to, that I did not expect it to be successful as a bell, any more than silver, merely because a bar of it will ring. But it was well worth while to try the experiment and settle it.

Still the question remains, what are the best proportions for the copper and tin alloy, which we are now quite sure, in some proportions, will give the strongest, clearest, and best sound possible? They have varied from something less than 3 to something more than 4 of copper to 1 of tin, even disregarding the bad bells of modern times, some of which contain no more than 10 per cent. of tin instead of from $\frac{1}{5}$th to $\frac{1}{4}$th, and no less than 10 per cent. of zinc, lead, and iron adulteration, as you may see in Ure's Dictionary, and other books. Without going through the details of the various experiments, it will be sufficient to say that we found by trial, what seemed probable enough before trial, that the best metal for this purpose is that which has the highest specific gravity of all the mixtures of copper and tin. It is clear, however, that the copper now smelted will not carry so much tin as the old copper did without making the alloy too brittle to be safely used. You will see from the table of analyses, which I shall give presently, that the Westminster bell contains less tin and antimony together, and more copper than the old bells of York Minster, and a great deal less tin in proportion to the copper than the famous bell of Rouen, which was broken up and melted into cannon in the first French revolution, and of which it is worth while to mention that it appears to have been commonly called the silver bell, though the analysis shows it had not a trace of silver in it. We found that the 3 to 1 alloy, even melted twice over, had a conchoidal fracture like glass, and was very much more brittle than 22 to 7 twice melted, or 7 to 2 once melted; and accordingly, the metal used for the Westminster bells is 22 to 7 twice melted; or, reducing it for convenience of comparison to a percentage, the tin is 24·1 of the alloy (not of the copper), and the copper 75·86, which you see is very nearly the same as the result of the analysis of the bell when cast. This may seem extraordinary, because it is well known that the tin wastes more in melting than the copper; but no doubt the explanation of it is, that the antimony which comes out with the tin in the analysis goes in with the copper in the composition, unless special means are taken to eliminate it, which is not worth while, as antimony produces the same kind of effect as the tin, and a little of it does no harm; as we know from intentionally putting some into a small bell, though it is an inferior metal to tin both for bells and organ pipes, in which I understand it is frequently substituted to stiffen the lead, because the English organ builders will not use as much tin as the old ones did, and the German ones still do.

This 22 to 7 mixture, or even 3½ to 1, which is probably the best proportion to use for bells made at one melting, is a much "higher" metal, as they call it, than the modern bellfounders, either English or French, generally use. As there is no great difference in the price of the two metals, the reason why they prefer the lower quantity of tin is, that it makes the bells softer, and therefore easier to cut for tuning, which is obviously a very insufficient reason. I advise everybody who makes a contract for bells, to stipulate that they shall be rejected if they are found on analysis to contain less than 22, or at any rate 21 per cent. of tin, or more than 2 per cent. of anything but copper and tin.

Analysis of several Bell-metals.

	Rouen.	Gisors.	York.	Lincoln.	Westminster.	
			Old Peal.	1610.	Top.	Bottom.
Copper . . .	71·	72·4	72·76	74·7	75·31	75·07
Tin (with Antimony)	26·	24·2	25·39	23·11	24·37	24·7
Iron	1·2	..	·33	.09	·11	·12
Zinc	1·8	1·	..	traces.	..	..
Lead	..	·4	1·77	1·16	traces	traces
Nickel . . .	..	..	·85	·58	..	..
Specific gravity .			8·76 ..	8·78 ..	8·847 ..	8·869 8·94

The founders were afraid that by insisting on so much tin I should make the bell too brittle. I was satisfied that if they cast it properly it would not be so; and I shall now give some proofs of that. The first is, that the bell has now been rung frequently with a clapper from two to three times as heavy in proportion to the bell as all the other large bells in England, and pulled sometimes by as many as ten men. Secondly, I have a piece of the bell, or rather of one of the runners at the top, which is always the least dense and the weakest part of the casting, about 2 inches square, and ·6 inch thick. I tried to break it in two with a 4 lbs. hammer on an anvil, both with and without the intervention of a cold chisel, and I tried in vain; whereas a piece of the Doncaster bell-metal, cast in 1835, which was exactly twice as thick, and therefore ought to have been four times as strong, broke quite easily under the first blow of the hammer, although it is at the same time softer, but of less specific gravity by something like 12 per cent., and visibly porous.

In fact, the metal of this bell is superior in this very important point of specific gravity to any bell-metal that I have examined, or have found any account of, and to the highest specific gravity which is given in any of the books for the densest alloy of copper and tin. The only exception to this remark is that, according to my weighing, the specific gravity of some small clock bells, made by a man of the name of Drury (who is now either dead or retired from business), was exactly the same as this, if not a little higher. But I do not profess to have done it with the same nicety as the bits of metal in this table (except the two first, which are taken from a book) were no doubt weighed with by Dr. Percy and Mr. Dick, at the Geological Museum, where also the analysis of this and the old Lincoln and York bells were made. And it is remarkable that there are no small clock bells to be got now, equal either in density or quality, to those of Drury's, who is believed to have had some secret mode of making them, as they contain nothing but the usual metals. It ought therefore to be made another condition with a bellfounder, that the specific gravity of his bells should not be less than 8·7; and this, you observe, is sensibly below any of the specific gravities in the above table, except the very bad metal of the Doncaster peal of 1835, which was always complained of as inferior to the old peal which it replaced, though the new peal was a heavier one. About a year ago, the founders of this bell were warned that it would not be passed by the referees, if the specific gravity came below this figure, at least unless we were so perfectly satisfied with its sound as to render further inquiry unnecessary; and I convinced them by a simple experiment, first, that it was easy enough to test the soundness of the casting without breaking it, and secondly, that such a thick casting would not be sound, or at any rate, not of proper density, unless the mould was made so hot as not to chill and set the outside of the metal too soon. I may add, that I knew before the weighing of the bits for specific gravity, that it must be high enough, from the gross weight of the bell, in proportion to its size and thickness; for if the specific gravity had been 8·7, instead of 8·9, the bell would have weighed 7 cwt. less,—a quantity quite large enough for calculation even in a bell of 16 tons. I remember that the man who came down from Mears's to examine the old Doncaster bells of 1722 for re-casting, underestimated the weight of the tenor by $2\frac{1}{2}$ cwt., no doubt judging of its weight according to what a bell of the same size and thickness would be when made of such metal as their new peal was.

This bell is also so elastic, that I can make the clapper of 13 cwt. strike both ways, pulling it alone, and therefore of course to one side only; which I never found the case with any other bell.

You will probably wish to hear something of the actual casting of the bell, which is by no means an easy operation, if we may judge from the much greater rarity of good large bells than of small ones. There was no bell in England above 3 tons weight, except perhaps the tenor of the peal at Exeter, equal to many that exist of half that weight. Sir Christopher Wren condemned and rejected the great bell of St. Paul's, for which the present was substituted in 1716; and that rejected bell was made by a founder whose bells, cast the same year as his St. Paul's bell, are still at St. Alban's, and are very good ones. The present St. Paul's bell is itself inferior to that of Bow and the old York Minster bells; and both the Lincoln and York Minster bells are feeble and unsatisfactory, though the same foundry, until the last 30 or 40 years, turned out many very good bells of smaller but yet considerable weight. The metal was twice melted, as it is for making speculums. It was first run into ingots of bell-metal in a common furnace, and then those ingots were melted and run into the mould from a reverberatory furnace, in which the fuel does not touch the metal, but the flame is carried over and reflected down upon it from the top, or dome over the melting hearth. The ingots were only in this furnace $2\frac{1}{2}$ hours before the metal was ready for running, as the alloy of copper and tin melts, as usual with alloys, at a much lower heat than the most obstinate of the two metals requires alone; and the whole 16 tons were run into the mould in five minutes. I understand that quick casting is essential to the securing of sound casting.

Messrs. Warner make their moulds in a different way from usual. First of all a hollow *core* is built up of bricks, and straw, and clay, and made to fit the inside of the bell by being swept over with a wooden pattern or *sweep*, turning on a vertical axis through the middle of the core. For bells of moderate size, they keep a number of different sized cores of cast iron, instead of building them up of bricks; and the iron cores are covered with the loam as before. They are easily lifted into a furnace to be dried and heated, whereas the brick ones must have the fire lighted within them. But the great difference is in the outside mould, or *cope*. Generally a clay bell is made on the top of the core, the outside being turned by another sweep turning on the same vertical axis; and when this is dry, a third fabric of clay and straw is laid on the outside of the clay bell, and this is called the cope. When it is dry it is lifted off, and the clay bell broken away; the cope is then put on again, and the metal poured in where the clay bell was.

Not only is this a very roundabout process, but without great care in putting the cope on again, the bell is apt to come out not uniform in thickness all round. I have seen broken bells twice as thick on one side as the other. Messrs. Warner's plan is to make the cope of iron larger than would fit the bell; that is lined with the casting loam, which is turned by an inside instead of an outside sweep, and the junction being between an iron plate at the bottom of the core, and the flanch at the bottom of the cope, they can be fitted together more accurately than the clay core and cope can be, and moreover bolted together, so as to resist the bursting pressure of the melted metal, instead of having to rely merely on the sand with which the pit is filled, and such weights as may be laid upon it. The core and cope were both made very hot before the pit was closed in with sand; for that is still necessary to prevent too rapid cooling, which makes bell-metal soft, and what you may call rotten in texture, and indeed if it is rapid enough, will make it malleable. This bell was kept in the pit 12 days before the sand was taken out, and even then the cope was too hot to touch, and it was left two days more before it was taken off. It has now changed its colour so much from the effect of the London damp and air, that you must trust to my statement, that until it came here it presented that peculiar mottled appearance which is so much admired in organ pipes, rich in tin; in fact, a gentleman who came to look at it immediately remarked its "fine silvery hue," with that inveterate propensity to discover silver in bell-metal which seems to defy all chemical refutation. It is remarkable that the tin does not show itself in this way, if it is less than about $\frac{4}{13}$ of the copper, *i.e.*, about 23 per cent. of the alloy.

I have now told you all that is likely to be interesting about the construction of this bell, so far as its shape and composition affect the sound. But the description would be incomplete without a short notice of another feature in the design, very subordinate indeed to those which I have yet spoken of, but still not insignificant: I mean the construction of that part of the bell by which it is to be hung. The common, indeed I may say, the universal method, for no other has been ever used for large bells, is to cast six ears or loops on the top or crown of the bell, which are technically called *canons*, and through which certain iron hooks and straps are put to fasten the bell to the stock. Small bells may be securely enough hung by a single canon or plug with a hole in it, like the common house or hand bells, or in any equivalent way. This method of hanging by canons had long appeared to me unsatisfactory on account of its weakness; for not only has this metal no very great tenacity lengthwise, but the canons are always the weakest part of the casting, from being nearest to the top; and, I believe, there are few old peals in the kingdom in which some of the bells have not had their canons broken, and replaced by iron bolts put through holes drilled in the crown. Moreover, this method of hanging makes it troublesome and expensive to turn the bell in the stock, to present a new surface to the clapper when it is worn thin in one place, and many bells have been cracked in consequence. A Mr. Baker took out a patent a few years ago for several new modes of hanging, for the purpose of enabling bells to be turned in the stock. The first is simply making a hole in the crown and hanging the bell by a single large bolt, which also spreads out into the staple to carry the clapper. The objection to this is, that nobody would like to trust the weight of a large swinging bell to a single bolt if he could use several instead; because, although a single bolt can of course be made large enough to carry anything, yet if there is any flaw or bad workmanship in it, the result would be something frightful with a large bell; at any rate, nobody who expressed an opinion about it on either of the two occasions when it was exhibited at the Institute of Architects, nor any one whom I have consulted about the making or hanging of the Westminster bells, nor indeed anybody anywhere whose opinion is worth mentioning, so far as I can learn, approves of such a mode of hanging a large bell like this, even though it does not swing, and therefore I declined Mr. Baker's invitation to adopt it. His other method, as described in a recent pamphlet and in his specification, is to cast a thickish pipe on the top of the bell, which is to go through the stock and be fastened with a large nut, just as his iron bolt was in the other plan: only the clapper bolt is now independent and goes through this pipe, and is held by another smaller nut on the top of it. This seems to me to combine the two vices of the weakness of canons and the risk of a single bolt in the most complete manner, with the addition of a thread cut on this bell-metal pipe, which is about as weak a construction as possible. I should think no person in his senses would use such a plan: in fact, Mr. Baker himself did not seem to contemplate using it, but only put it into his patent, as patentees do, with the object of securing possession of every possible new method of doing the thing in question they can think of: but as patentees also do sometimes, he left out at least one method which is better than those which he put in, and that is the following.

On the top of the bell is cast what has been called a button and a mushroom; and either name will do well enough, except that a mushroom has not a hole through it, and buttons have more than one. It is in fact a very thick short neck, with a strong flanch round the top, which is fastened to the stock, in moderate sized bells, merely by bolts with hooked ends; and in very large ones, by bolts passed through a collar, bolted together in two pieces. The clapper (if there is one) is hung by a separate bolt, which goes through the hole in the neck and through the stock; and it has nothing to do with carrying the weight of the bell, unless you like to make it with a shoulder, so as to help the outside bolts. By this method you hang the bell by a lump of its own metal as large as you choose to make it; and besides that, when the bell is worn in one place, it can be turned round to present another after you have loosened the bolts a little. Clock hammers wear the surface of a bell so little compared with ringing, that these Westminster bells are not likely to want turning for 50 or 100 years, and therefore in this case that advantage is not of so much consequence as usual, or as obtaining the safest possible mode of hanging; but as the power of turning happens to be consistent with hanging the bell in the strongest way, we all agreed in adopting this, except that the founders rather regretted the loss of the canons as an ornamental finish to the bell. Anybody who has happened to read the aforesaid pamphlet, which Mr. Baker has very diligently circulated, will see his drawings of all the three methods, (I mean his own two patented methods, and my unpatented one,) and will see also that he has persuaded himself, after the manner of patentees, that my "mushroom" (the name which I think he himself gave it), held up under the stock by four or six bolts, is identical with his pipe going through the stock, and fastened on the top by a nut,—a point on which I have heard yet no opinion but one, that his own drawings are the best answer to his claim.

I shall conclude by giving you as complete a list as I have been able to make out, of all the large bells in the world, except in China, where the bells are of a different and inferior form. It is substantially the same as that given in the *Lectures on Church Building* before referred to, but with a few additions and corrections. I do not believe that the recorded weights of several large bells can be correct, because they are inconsistent with the dimensions, which are much more likely to be right. The bells of Sens and Exeter especially, cannot possibly weigh as much as is stated for them, viz. 15 tons and 5½ tons respectively. Indeed I am so convinced of that, that I shall put them in the table at 13 tons and 4½ tons, and I believe that will be above the real weight rather than below it. The Erfurt bell may, perhaps, be as heavy as is stated, because I believe it is a thick one; and from its celebrated quality, the specific gravity is certain to be high. I doubt whether the Paris bell is as heavy as that of Montreal, because its diameter is the same, and its thickness less throughout. To be sure, the specific gravity of the Montreal bell is probably no better than that of the late Doncaster bell-metal, from the same foundry; and therefore I have left the reputed weight in the table for the Paris bell, though from other calculations I still doubt its accuracy. On the other hand, I am certain that the weight of the two great Russian bells is very much underrated. There can be no mistake about the thickness of the large one, because a piece is broken out high enough for a man to walk through upright, and as I said before, the shape so nearly agrees with that of our bell, that the weight cannot be very different from that given by the ratio of the cubes of the diameters, and that would make it nearly 250 tons, which I suppose is much the largest casting in the world. And the other Russian bell, being 18 feet wide, must be 110 tons, according to the Westminster scale, instead of 64, which is the recorded weight. I might have added several other Russian bells to the list, from Lyall's book, all of great weights, but it seemed hardly worth while, as everybody knows already that the Russians have surpassed all the world in the magnitude of their scale of bellfounding, and two or three instances prove as much as twenty. I have stopped the list at four tons. After these would come the single bells of Canterbury, Gloucester, and Beverley Minster, and the tenor bells of the peals of Exeter and York, St. Mary-le-Bow, St. Saviour's, and Sherbourne, which run from 3½ to 2½ tons.

List of Bells.

BELLS.	Weight.		Diameter.		Thickness.	Note.	Clapper or Hammer.
	Tons.	Cwt.	Ft.	In.	Inches.		
Moscow, 1736 broken, 1737	250	?	22	8	23	..	..
Another, 1817	110	?	18	0	..	..	$\frac{1}{33}$ of bell.
Three others	16 to 31		..		..	..	..
Novogorod	31	0	..		..	..	..
Olmutz	17	18	..		..	..	..
Vienna, 1711	17	14	9	10	..	..	..
Westminster, 1856	15	18½	9	5½	9⅜	E.	12 cwt.
Erfurt, 1497	13	15	8	7½	..	F.	..
Paris, 1680	12	16	8	7	7½	..	6½ "
Sens	13	?	8	7	..	..	..
Montreal, 1847	12	15	8	7	8½	F.	..
Cologne, 1448	11	3	7	11	..	G.	..
Breslaw, 1507	11	0	..		..	..	..
Gorlitz	10	17	..		..	..	..
York, 1845	10	15	8	4	8	F sharp.	4 "
Bruges, 1680	10	5	..		..	G.	..
St. Peter's, Rome	8	0	..		..	..	..
Oxford, 1680	7	12	7	0	6⅛	..	80 lbs.
Lucerne, 1636	7	11	..		..	G.	..
Halsberstadt, 1457	7	10	..		..	..	..
Antwerp	7	3	..		..	..	..
Brussels	7	1½	..		..	G sharp.	..
Dantzic, 1453	6	1	..		..	..	..
Lincoln, 1834	5	8	6	10½	6	A.	150 "
St. Paul's, 1716	5	4	6	9	..	A.	180 "
Ghent	4	18	..		..	..	..
Boulogne, new	4	18	..		..	..	..
Exeter, 1675	4	10 ?	6	4	5	A.	75 "
Old Lincoln, 1610	4	8	6	3½	..	B flat.	..
Fourth quarter-bell, Westminster, 1857	4	0	6	0	5¾	B.	..

E. B. D.