thick. The brickwork of the smaller wells was 2 ft. thick; that of the larger wells was $3\frac{1}{2}$ ft. thick. It was composed of specially made radiating bricks, set in mortar, consisting of one part of stone lime, two parts of kunkur, and six parts of fine brick-dust, the whole well ground together. The wells were successfully sunk through artificial islands. They were filled with concrete and connected by small arches. The superstructure of the piers was $27\frac{1}{2}$ ft. long, $7\frac{1}{2}$ ft. wide, with semi-circular cutwaters. They were carried up 21 ft. above low water. The abutments were founded on three wells, each $12\frac{1}{2}$ ft. in diameter, and were similar to the piers, but flanked with longitudinal wing walls. Nearly nine wells were sunk per month. A spur of earth and bowlders, 4,800 ft. in length, was made from the left abutment of the bridge to the high ground forming the left bank of the river, as a protection against the river getting in rear of the bridge abutment. Moreover, an average amount of 13,467 cubic feet of bowlders had been thrown round each of the piers. The bowlders formed a local supply of material ready to be dropped into any holes scoured out around the piers, and gave support to the piers to resist the overturning action of the stream. The superstructure was composed of a pair of lattice-girders, connected on the top by an upper roadway of cross-girders and rail-bearers, covered by buckle and flat plates, braced on their under sides. This upper roadway carried the railway and two footways. There was a lower roadway for foot passengers and mules and ponies only. A detailed account was given of the girders and roadways and of the erection of the girders. The total cost of the bridge, including the protective works, had been £139,502, or £28 11s. per lineal foot.

CURVED BEAMS.

On Trajan's column, at Rome, has stood since A. D. 114 the sculptured representation of that Emperor's bridge over the Danube, which (like the construction of the column itself) dwarfs modern efforts, with few exceptions, by its colossal nature. The bridge was 3,000 ft. in length, and had twenty-two arches of timber, so that it is not going far aside to allude to it in a notice of curved beams.

They are of four classes or systems of formation, namely, the scarfed, the bent, the flitched, and the laminated. The first consists in making a curved beam out of straight logs, and is probably an ancient plan, of which the use has been occasional during a long period, or, if sometimes forgotten, as frequently revived. Palladio used such beams, and may have received the idea from the sculptured record on Trajan's column. About a century ago the Brothers Grubenman, of Switzerland, were famous, and the arched ribs used by one of them in a bridge at Wettenghen were of formidable dimensions. The space being 230 ft., the beams were composed of seven logs in depth, with serrated tabulations throughout the length, so that the camber could be obtained without any actual bending of the wood. The heading joints in each layer were 12 ft. apart, but so arranged as to form an interlacing bond, and the whole was strongly keyed and bolted. It was ligneous masonry.

The following account, "published under the superintendence of the Society for the Diffusion of Useful Knowledge," is too remarkable an instance of the difficulty encountered by ordinary literati in describing technical affairs to be neglected:

STRAIGHT LOGS CURVED IN THE TABLING.

"The abutments were 25 ft. high, and the arch between them was a catenary—that is, the same form which a rope or flexible chain assumes by its own weight when hung over two fixed pegs. This arch was, of course, inverted in the same manner as the iron chain bridges that have lately been constructed in this country, and, making allowances for the difference of materials and the mode of junction, it may be fair perhaps to consider it as the first chain bridge that ever was constructed in Europe."

Misled by the idea of a catena, the writer failed to reflect that it would be as difficult to suspend an arch of timber convex downward as to erect a flexible chain of iron, convex upward. My illustration is not drawn from a particular example, but is intended to represent the serrated tubing referred to, and which was attended with a waste of material, equal to one-third of the total quantity consumed. The large volumes of Krufft and Emy afford more express and extended information on this bold and powerful form of combination than I can propose to present.

The second class began early in the present century, when M. Wiebeking, an able German constructor, effected an important improvement. He contrived to bend to the requisite curvature timbers as large as 15 ins. square and 50 ft. long, thus reducing the number of heading-joints and the waste generally attendant on short pieces. For when the grain could be forced into the direction of the curve, the great labor of the serratures and the loss of material they occasioned could be at once avoided. The qualities of economy and grace were thus added to the masculine character of earlier work. With the same artist also originated the practice of increasing the depth by additional logs as the beam receded from the crown—an expedient that has been fully approved by science and experience. Mr. Herman Haupt, A. M., of New York, for instance, who, from his knowledge of American examples, is well entitled to speak, says "the lightest and most simple system, and the one best calculated to attain the maximum limits of span, consists in a solid beam of parabolic curvature, increasing in depth from the vertex to the ends."

A figure will be given in the next chapter, but nothing could more exactly illustrate this description than the beams employed by Mr. Wiebeking in the bridge at Bamberg in 1809. The span is 208 ft., and the rise 17 ft. The beams are three logs in depth at the crown, and five at the springing, keys being introduced in the longitudinal joints to prevent sliding. Beams compacted on this plan of bending the fibers are probably more vibratory than where the parts are cut to the requisite shape, according to the old rule, and this property must increase with the length in either case. There are several American examples of more than 300 ft., and that of Grubenman over the Linnant, at Wettenghen, was 390 ft. The components may, in fact, be multiplied to any extent, and the crushing point of the material marks their

only limit. But when beams of enormous dimensions, and exposed to the disturbance of moving loads, are supported by stone abutments, the most careful provision ought to be made, lest they crush the mortar and fracture the masonry. Esthetics have a higher standard now than at the beginning of the age, and when beams constitute the leading elements of structures, it seems only fitting that their forms should be displayed. Casing has no greatly preservative effect, and when made to imitate stonework, degenerates into an unworthy deception. The carpenter owes some devotion to his proper material, and it affords an ample range for his ability. If less monumental than stone, it is oftener available, and he who might almost span the Thames in a single bow may well leave to the Arno and to Florence, unimpaired, the moderate yet many-centered elliptics of St. Trinità.

With regard to the third class, or flitch beams, exact information exists. It was the invention of a French architect of the first celebrity, the contemporary of Palladio. He traveled in Italy, probably visited the great Vicentine, and studied his works. Returning to France, L'Orme soon acquired especial *éclat* from this constructive novelty. "We have no further need," said he, "of great trees for the beams

and rafters of our roofs, for they may be formed of ribs that will seem to grow out of the walls." His mode was this: Stopping the inner portion of the wall at some distance below the eaves, he placed on the bed thus formed a strong wall plate, with mortises at proper distances. At these intervals he raised ribs constructed of two thicknesses of boards of equal lengths and breadths, but commencing with a half length on one side, so as to make the abutting joints alternate. These boards being pinned and keyed together formed a rib of considerable stiffness, and commonly of semicircular shape. Supplementary ribs were added at the eaves and apex when requisite. Three boards were sometimes joined, and the strength proportionally augmented. It was no ephemeral contrivance, to be laid aside as soon as novelty was over, but one that has maintained a permanent place in the carpenter's repertory. In proof of this, it is only necessary to instance their use by Mr. Decimus Burton, in the dome of the Colosseum, so long a striking feature of the Regent's Park, but recently taken down. They appear also at frequent intervals in the temporary erections for exhibitions, and other works of great capacity, where the effect is occasionally enhanced by transverse members of ornamental character. The facility with which any form of arch, pointed or otherwise, can be produced, is a prominent merit of the flitch method.

Mr. Price, in his "British Carpenter," recommended curved beams on the flitch principle for bridges; but that is an application for which they are ill-suited. Neither the headings nor the lateral cohesion can be regarded as trustworthy under a strain of much severity; though for carrying a light load, such as temporary roofing and skylights, over a large space, these beams are eminently convenient. Mr. Price was not the first to conceive them, nor was any British carpenter. They are due to the eminent Frenchman above named, and in L'Orme's "Nouvelles Inventions pour Bien Bastir," A. D. 1561, are to be found, in addition to very numerous exemplifications of the kind, indications of arches made by two thicknesses of boarding, bent concentrically on the flat.

Whether through the survival of this suggestion, or the natural development of Wiebeking's system, modern constructors have produced beams perfectly distinctive in character and name from the whole-timber and the flitch classes. This fourth sort, being compacted of thin planks or boards, are called "laminated," and are described in the "Nouveau Système d'Arcs pour les Grandes Charpentes, par A. R. Emy, Paris, 1828." They were introduced here in railway bridges by Messrs. Green, of Newcastle, in 1837. The example best known in London, however, and probably the neatest anywhere produced, was that by Mr. Lewis Cubitt, at the terminus of the Great Northern Railway, King's-cross. The station, 105 ft. in width, was spanned by semicircular ribs, 11 ins. wide and 12 ins. deep, made of nine thicknesses, and moulded at the angles. On the haunches next the walls were open spandrels of iron, and there were extra laminations of wood at the crown, 9 ins. wide and 12 ins. deep. The distance between the principals was 20 ft., and their simple figure and accompaniments produced a remarkable impression of strength, lightness, and economy. They are represented in the later editions of Tredgold's "Carpentry," "Gwilt's Cyclopædia," and "Weale's Rudimentary Series" (the "Art of Building"). Unfortunately, the confined hot vapor from the engines proved destructive, and the wood has been replaced by iron substitutes.

These several methods offer to the modern carpenter a great choice of means, of which he can avail himself according to the nature and conditions of his works, but in

all I would again venture to suggest the use of iron screws, of which the thread should cross the joint and draw the surfaces forcibly together. Having at the same time an eye to the possible effect of shrinkage, it may be judicious to connect only two thicknesses with the same screw.—*Building News.*

KEIR EXPLOSIONS.

By WILLIAM NANSON, Bondsville, Mass.

A FEELING appears to be prevalent among bleach and print works managers that the use of high pressure or Barlow keirs is unsafe, on account of their liability to explode. The danger, I think, is overestimated, for if we examine carefully into the probable causes that have led to such explosions, we shall find that they are easily avoidable, and, therefore, that it is incorrect to assume that high pressure keirs must be dangerous at all times and under all circumstances. But it is nevertheless true that high pressure keirs have exploded, with all the disastrous effects incident to a steam boiler explosion, and therefore I shall endeavor to show in the present paper the causes which may lead to the generation of forces sufficient to explode a keir, how these forces may be liberated into activity, and how the generation of such forces may be avoided and all danger of explosion effectually prevented. By way of illustration, I shall take the case of a keir that burst at the print works of the Messrs. Prokoff, at Moscow, Russia.

The keirs in question were 11 ft. 6 ins. long and 6 ft. 6 ins. diameter, made of $\frac{5}{8}$ in. iron; the joints were single fished butt joints, running in the direction of the length of the keir. These joints were single riveted with $\frac{5}{8}$ in. rivets, the rivet heads inside the keir being countersunk. Each keir was furnished with a steam gauge, back pressure valve, and a 3-inch safety pipe set to blow off at a pressure of 50 pounds per square inch.

Being at the works myself shortly after the explosion took place, I was enabled to examine the various parts of the broken keir, and also to make minute inquiries regarding all the attendant circumstances.

An examination of the torn edges of the plates showed the iron to be in good condition, strong, and fibrous, and subsequent tests proved it to possess an ultimate cohesive power equal to about 50,000 pounds per square inch section. Now if we take one-third of this as being the *permanent* tensile strain the iron would bear without injury, and find the steam pressure equivalent to such a strain, it would show us that the keir could be worked at a pressure of 133 pounds per square inch with safety, and that we should have to reach a pressure of 212 pounds per square inch to burst the keir. It must be understood that such a pressure of steam could not exist, because in the safety valve we have an outlet 3 inches in diameter which would relieve the pressure whenever it exceeded 50 pounds per square inch, and the boilers which supplied the keirs with steam were never worked at a pressure of over 55 pounds per square inch, hence it will be safe to infer that over-pressure of steam could not be the cause of the explosion.

If we take into consideration the fact of the joints all running in a line with the weakest portions of the keir, viz., in the direction of its greatest length, and the loss of binding force in the rivets by countersinking, and the probable shearing strength of single rivets subjected to such a direct strain, it will be at once seen that the joints were by far the weakest portions of the keir, and we can easily come to the conclusion that if the pressure which burst the keir had been a gradually accumulative one, it would have torn the plates asunder at the line of rivets. I found, however, that the lines of fracture ran in all directions. They did not radiate from any given point, neither did they run with or even parallel to the lines of rivets, but, on the contrary, in all cases where the lines of fracture had intersected the lines of rivets the fish plates had offered no perceptible opposing force, but were torn across in the direct lines of fracture. It should also be borne in mind that the ease with which a 3-inch safety pipe would relieve any over-pressure renders inadmissible the theory of any *gradual* accumulation of pressure either from steam or other causes; therefore I think it will be safe to conclude—first, that the keirs were in good condition, and well able to withstand any steam pressure which it was calculated they should bear; second, that the keir was not exploded by steam pressure; and third, that whatever forces were generated to cause the explosion must have been brought into activity instantaneously. Hence, in order to establish any theory regarding the explosion based upon any supporting evidence, it will be necessary for us to look to other causes than steam pressure, wear and tear, or imperfections in the construction of the keirs.

The keirs in question exploded during the process of "bowking," or while the goods were being boiled in a liquor composed of 800 gallons of water, 360 pounds of soda ash, and 150 pounds of resin, the soda being almost a pure carbonate. Any elementary work on chemistry will tell us that carbonic acid is liberated from its compounds by any acid stronger than itself, and that it is the weakest of all acids. Therefore it will be readily understood that the presence in the keir of any substance having a decided acid reaction would decompose the carbonate of soda and set the carbonic acid free, and it is to this process of liberation that we may trace the first elements of danger. There are several ways by which we can account for the presence of sufficient acid in the keir to liberate the carbonic acid gas from its base. In the first place, the goods may not have been thoroughly washed after the previous operation of "souring," and a large quantity of free acid may in this manner have passed into the keir with the goods. Another and more probable theory is that the decomposition of the carbonate of soda and consequent liberation of the carbonic acid was due to the action of the resin, as it is known that resin contains two compounds having a strong acid reaction, and each capable of displacing carbonic acid.

It is a recognized fact that when resin and soda are boiled together in the ordinary manner very little chemical change takes place; the action is almost wholly a mechanical one, the particles of resin being merely held in suspension in the liquor, although it is certain that sufficient chemical action does take place to cause the evolution of a portion of the carbonic acid, and should the liquor be violently agitated or raised to a higher temperature, the evolution of the gas increases directly as the increase of the heat. There is no doubt that at a temperature such as would exist in a high pressure keir the resin would be acted upon more energetically, and it is possible that a temperature might be finally reached at which the hydrocarbon constituents of the resin might become partially or wholly volatilized, and the acids combined with them be thus liberated into powerful action. The result would be the energetic decomposition of the carbonate of soda, and the consequent generation of a large volume of carbonic acid gas. If we take into consideration

the limited room for expansion in the keir more than two-thirds full of cloth and liquor, working at a pressure of 45 pounds per square inch, and increase this pressure by bringing into active force the carbonic acid gas contained in 360 pounds of carbonate of soda, we should create a pressure far above the bursting point of the keir, because it must be borne in mind that the increased strain would be an impulsive one, being produced instantaneously, and that all impulsive strains are equal in force to double the same load laid on gradually.

I have already shown that the safety valves and other conditions of the case preclude the possibility of a gradual accumulation of pressure either by gas or other causes, therefore it is necessary to show how the gas can be liberated into activity instantaneously. There are two methods by which this might be accomplished—first, by the generation of a certain degree of heat sufficient to suddenly decompose all the chemical compounds in the keir, and which is hardly probable; and secondly, by the sudden removal of the pressure.

Carbonic acid gas is easily soluble in water even at the ordinary pressure of the atmosphere, and it becomes more soluble as the pressure is increased. Even the gas itself may be compressed into a fluid state, and if the pressure be removed the gas is immediately liberated and expands to its normal condition. (This can be illustrated by loosening the cork from a bottle of soda water.) If, therefore, we mix the gas with water at a pressure of three atmospheres, such as would exist in the keir, a large volume of it would be taken up by the liquor, and remain in a quiescent condition until a removal of the pressure, when it would be suddenly liberated and expand into forcible action. Hence, though the action of the resin may be producing a continually increasing volume of carbonic acid gas, the gas may be taken up and remain combined with the water until a favorable moment arrives for its liberation, and there is little doubt that the most favorable opportunity for this to occur would be a sudden reduction of the pressure.

This reduction might be effected by either of the following causes—first, by the sudden condensation of the steam in the upper portion of the keir, and the consequent conversion of the whole of the liquor into steam and carbonic acid gas. This, of course, could only occur through gross carelessness, such as directing a stream of cold water on the outside of the keir, which I have known to be done for the purpose of washing off the lime and other impurities. The other and most probable theory is that the attendant, in changing the liquor from the full keir to the empty one, waited too long before opening his liquor valve, and thus allowed the pressure in the empty keir to become much lower than the pressure in the keir upon which the steam was acting and which contained the liquor. Consequently the sudden opening of the valve and instantaneous liberation of the pressure caused the violent evolution of the carbonic acid gas simultaneously with the forcible entry of the steam and liquor. Of course it must be understood that both keirs were full of cloth, and that in speaking of the empty keir I mean the one in which there was no liquor.

The following diagram will illustrate my meaning more fully:

Supposing these keirs to be full of cloth, and to have been working about four hours, and the steam to be entering at the valve, a' , in the keir A, and the liquor to be all over in the keir B; the attendant, in changing the liquor back into the keir A, would turn off the steam at a' , and turn it on at b' , and, after waiting a few moments to allow the pressure to increase in the keir B, to be greater than that in the keir A, he would open the valve a' , to allow the liquor to pass from B to A, as indicated by the course of the arrows. Under all ordinary circumstances, if the pressure in the keir B was 45 pounds, the pressure in the keir A would be about 35 pounds, the difference between the keir carrying the steam and the keir receiving the liquor being usually about 10 pounds; hence we see that under ordinary circumstances the actual pressure removed in changing over the liquor is only 10 pounds; but if the attendant wait too long before opening the valve a' to let the liquor into A, the pressure in A becomes rapidly diminished by condensation, and it might be possible for him to neglect it for a sufficient length of time to reduce it to the ordinary pressure of the atmosphere, and of course as we diminish the pressure in the keir A we diminish the force opposed to the liberation of the gas when the valve a' is opened to admit the liquor. The probability of this theory is strengthened by the fact that the keir did explode a few moments after the attendant had opened the valve a' , and all the other keir explosions that have come to my knowledge have occurred under precisely similar conditions; therefore I think it will be safe to infer that keir explosions may be attributed to the generation of carbonic acid gas, that the carbonic acid must be brought into active force instantaneously, and that its sudden liberation is due to either the presence of a high degree of temperature sufficient to suddenly decompose all the chemical compounds in the keir, or to the sudden removal of the pressure, the weight of evidence being decidedly in favor of the latter theory.

Now at a dye works, where no resin is used in boiling, there is no danger, and no explosions have ever been known to occur; but at a print works, where the use of resin is necessary, all danger can be effectually prevented by using the soda in a caustic state. Caustic soda contains no car-

CANADIAN EXHIBIT AT THE PARIS EXHIBITION.

bonic acid, therefore none can be liberated; and with a full knowledge of these facts before us, I should unhesitatingly say that, if there is no fault in the construction, there is no more danger in a high pressure keir than there is in an ordinary wooden keir with an open top.

THE PARIS EXHIBITION.

FRANCE occupies a larger amount of space than all the other countries combined. The palace of the Trocadéro will, it is true, be partly occupied by certain foreign contributions, but it is essentially a French portion of the Exhibition. With the exception of the pavilions of China, Japan, Tunis, Persia, Norway, and Sweden, and one or two others, all the buildings in the Trocadéro grounds are French. The principal annex is the Algerian Palace, a noble structure in which are collected the various exhibits of the colony. The exhibits of railway material, civil engineering, forest products, and constructive material, the two great pumping stations, and a variety of conservatories, complete practically the list of structures on this side of the Seine. The greatest pains have been taken to develop to the utmost the garden space available, for in the Champ de Mars the ground is so crowded with annexes as to leave little opportunity for picturesque effect. In the Main Exhibition Building of the Champ de Mars, France occupies the whole of one side, the vestibule opposite the Ecole Militaire, and one half of the vestibule facing the Seine. Outside the main building there are five French boiler-houses; the two grand French annexes for machinery, with the Bureaux d'Administration between

them; the annex for life-saving appliances, pumping machinery, and ports and commerce, facing the Seine, while a multitude of small buildings for French exhibits crowd the grounds. In the center of the Champ de Mars is the magnificent building of the Ville de Paris, in which France occupies the largest space in the galleries of the Fine Arts.

Next in importance comes England, occupying the post of honor, not only of the building, but sharing with France half of the Grand Vestibule, which will be worthily occupied by the Indian trophies of the President Prince of the British Commission and the exhibits of our great Eastern Empire. The Australian colonies and Canada fill the corner pavilion, and Canada has raised in the center the beautiful trophy of which we publish an engraving. This trophy, 100 feet in height, is an exhibit of all the useful timbers in the Dominion, and of slate and other building materials. Its galleries, moreover, are utilized for the display of general objects. Canada has, moreover, a large space in the industrial sections, and an annex in the grounds, as well as the building constructed by Messrs. Cubitt, and generously given to the use of the Dominion at the suggestion of the Prince of Wales.

The British exhibits will not be unworthy of the country and its colonies; and though we may perhaps naturally forget the importance of the collections of other nations, we cannot avoid the conviction that the position allotted to Great Britain represents fairly the part she plays in this Exhibition. As for annexes, we have the long agricultural shed, well adapted for the purpose of display, but not ornamental;