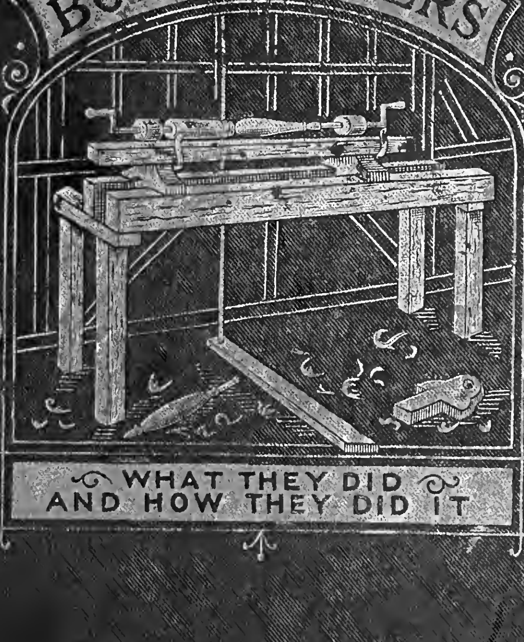
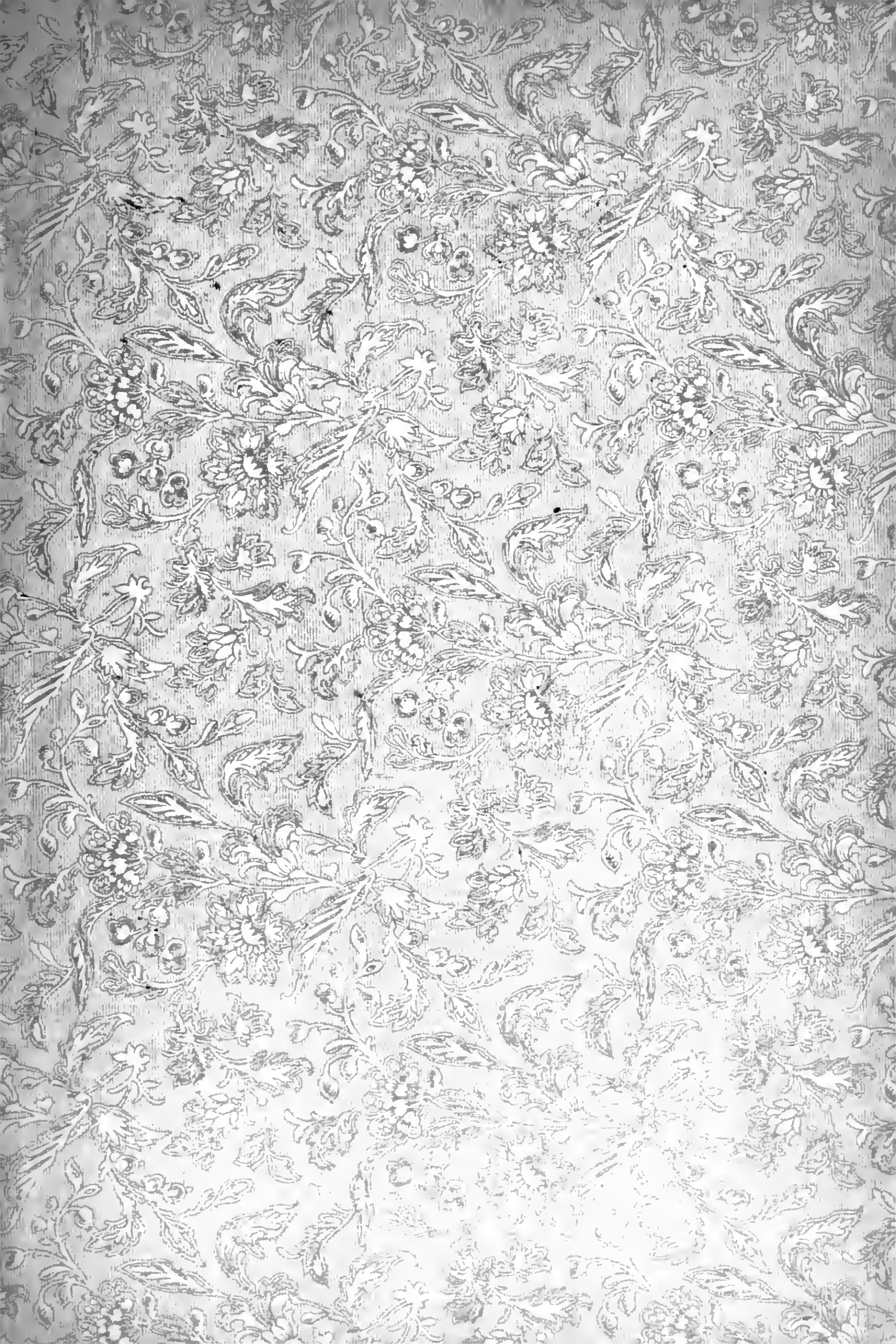
THE BOY ENGINEERS



WHAT THEY DID
AND HOW THEY DID IT



THE BOY ENGINEERS

WHAT THEY DID

AND

HOW THEY DID IT

A Book for Boys

BY THE

REV. J. LUKIN

AUTHOR OF "THE YOUNG MECHANIC," "AMONGST MACHINES," ETC. ETC.

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PREFACE.

IT is perhaps of no great importance to the reader to know how the outline of the following narrative came into my possession. Perhaps the surgeon who is spoken of in the introductory chapter placed it in my hands, and perhaps he did not; but it was in any case lawfully my own, to do with as I pleased; and I therefore put it into book form for the benefit of my old friends, THE BOYS. In doing so, I found it necessary to add considerably to it, and so to modify it that, while relating what the BOY ENGINEERS said and did, I might from personal knowledge of the mechanical arts assist the youngsters in their work. The volume, therefore, will be found to contain something more than a record of Boy Engineering, while, at the same time, there is no work described in it which a persevering and industrious lad might not accomplish. I therefore hope that not only will my young readers become interested in the tale of what was done by these youngsters, but themselves make trial of their skill in the construction of similar works.

J. L.

CHAPTER I.

INTRODUCTORY.

DURING the time of my residence at the village of Brampton, in the year 18—, I became acquainted with two brothers who were being educated at Huntingdon Grammar School, about four miles distant. They were the sons of a retired captain in the Royal Navy, who, although by no means rich, had sufficient means to live in comfort. His name was Addison, and the boys Henry and Arthur were better known as Harry and Tim, the latter name scarcely agreeing with that which his godfathers and godmothers had given him when he submitted, under somewhat noisy protest, to the baptismal rite. For a long time I could not divine the origin of his assumed name, but I subsequently discovered that it was derived from one Timothy Potter, an itinerant mender of pots, pans, and umbrellas, with whom my young friend held frequent commercial intercourse as a vendor of divers articles needed in his trade. It was old Tim who supplied solder, and wire, and odds and ends of tin and brass wherewith Arthur and his elder brother practised various handicrafts after their own fashion. For these and similar articles Henry seldom dealt personally with the tinker, not because he was too proud, but because his colleague was a better hand at driving a bargain, and did not object to any amount of higgling, so that he obtained his object in the end. I'm afraid, however, that, after all, old Tim beat young Tim sadly at these transactions, and made a very handsome profit, even when he declared that he was selling under cost price; especially as I had reason to think that the old tinker sometimes obtained his wares without paying for them at all.

My acquaintance with these lads originated in professional attendance rendered for a somewhat severe cut which Harry had inflicted on himself with a chisel in some carpentering operation. I found him not only a courageous boy who could bear pain without flinching, but an extremely ingenious youngster at mechanical work, and (which is not always the case) one exceedingly anxious to acquire information both in the theory and practice of engineering. His younger brother shared this predilection, and was in some respects the neatest hand of the two in actual work, though somewhat behind Harry in theoretical knowledge. Being myself fond of mechanics, and the possessor of a lathe and other simple requisites, we naturally struck up a friendship; and perhaps the loss of my own son, who was an only child, tended to draw my affections towards two lads who were by no means unlike him in disposition and tastes, and of whom, moreover, the youngest was not very dissimilar in personal appearance. Both the boys subsequently rose to eminence in their profession, but the eldest died comparatively young, having specially intrusted to my care an autobiography of his school-days, which I shall now present in a modified form to my readers.

"We had," says the writer, "an old wooden outhouse, adjoining the school, which had once served as a fowlhouse, but the feathery tenants had long since had notice to quit, and their home had not been transferred to new occupants. Tim and I cast many a longing look at the old shed, for it was little else, and had fancied that it might be converted into a very tolerable workshop by a moderate outlay of hoarded pocket-money, if we could but persuade our worthy schoolmaster to let us have it. For some time, however, we could not make up our minds to prefer the request, but contented ourselves with practising a little diplomacy, by keeping out of all mischief, and working zealously at our respective tasks. Having thus established a good character, which we managed also to retain, we determined on writing a joint petition, and we further proposed to do this in choicest schoolboy Latin. Having obtained a sheet of foolscap, as looking more official and business-like than notepaper, we began, after much consideration, as follows :—

" 'Domine Reverende et Doctor præstantissime,—Nos tui alumni (vix adhuc scholares appellari digni) quibus naturâ cacœthes studiorum attinet, quæ ad machinas fabricandas pertinent.'

" 'Oh, hang it,' said I, 'we shall never get to the end of the letter, Jim. I don't think 'tis bad grammar exactly, so far; but I am in a hurry to come to the point, and for the life of me I can't find out the Latin for workshop, or fowlhouse, or padlock. "Gallinæ domus," I suppose, would do for henhouse; but I vote we chuck up Latin and try English; or, what is better than either, let us write home and ask father to come and see us, and then we can tell him to ask the Doctor.'

"And so it was settled, and the ultimate result was that we got the shed made over to us, and an advance of pocket-money to repair it; and henceforth we had a terrestrial paradise of our own under lock and key.

"Luckily for us the other boys could not get near our workshop without going into the Doctor's garden, which garden was tabooed, as it contained a good assortment of fruit-trees, which would have been apt to shed their produce into the pockets of the pupils instead of those of the owner, if a right of way had once been established. As for us two, we were put on our honour, which boys as a rule observe a deal better than garden walls and fences; and though we were not unconscious of raids by outsiders, which at any rate tended to thin out the fruit, we ourselves had no part in these predatory excursions, nor did we ever consent to receive any share of the plunder.

"Let me describe our workshop and its contents before I pass on to tell of the various works executed therein.

"Not, however, that all was possessed at once, far from it; and many a treat did we give up, in which the rest of the boys participated, in order to obtain some much-coveted tool or appliance to add to our stock-in-trade. The shed, now weather-tight and clean, was about twelve feet long and ten wide, and was of ample height, and comfortably thatched. At one end was a window formed of an old cucumber-light, which we had picked up a bargain, and framed by laying it on its side, and securing it to a convenient beam which formed our window-sill. A similar window, formed of some neglected cottage casements placed side by side, and newly leaded, was fitted in one of the longer walls, and a padlocked door at the end gave access to the interior. We thought it would look well to put a notice on this door of 'NO ADMITTANCE

EXCEPT ON BUSINESS,' to which was subsequently added, to scare away passing tramps, 'BEWARE OF THE BULLDOG,' an invisible mythic animal, supposed by a pleasing fiction to be housed within. We tarred the whole of the outside of our workshop, *dignitatis et honoris causâ.* A roughly-made carpenter's bench occupied the space in front of the side window, over which we fixed our rack for carpenter's tools, the squares and saws, and similar instruments hanging on nails, and the planes being ranged on a shelf above.

"In order to ensure tidiness and order, which we rightly believed of great importance, we agreed to fine each other for leaving tools out of place, or unduly damaging them; and these fines, dropped fairly and faithfully into a money-box, were always expended upon new tools and materials.

"The first time we opened this box, which we did once every six months, we found ourselves able to buy a grindstone which happened to be for sale in the village, and had long been vainly coveted. It was a good stone, but most decidedly of a very eccentric character, as it had been badly used, and had a piece broken off one side, if a circular object has a side at any part of its circumference. However, we determined that our grindstone should at any rate not disgrace our workshop, and we therefore proceeded to correct it.

"Knocking out the already loosened wedges which kept the axle in place, we laid it upon its side on the floor, and drove also into the floor, through the square hole in its centre, a peg of wood cut to fit it easily but closely, into the middle of which we inserted a bradawl, which was first passed through the end of a lath. Having found, by turning the lath round upon this bradawl as a centre, the utmost size to which the stone could be trimmed, we completed our beam-compasses by inserting a nail at the required distance, with which we easily marked a circle upon the upper part of the stone. We found we could still save the greater part of it, and obtain a grindstone fifteen inches in diameter; the face, moreover, was rather more than three inches wide, quite sufficient for grinding our plane-irons, or even our light hand-axe. We then got a mallet and chisel on loan, and with much patience and care we managed to chip off little by little all that was outside the marked circle, and thus reduced our stone to shape, ready for mounting."

I may perhaps digress here to tell my young readers how the grindstones are cut from the quarries, as it is just one of those operations which the majority of those who buy and use these articles know nothing about. At the time of my young friends' purchase, in fact, I chanced to be staying at the Rev. Doctor's, and having the run of their workshop, I found them at work as above described, and gladly gave them the information which I now submit to the eyes of the readers.

The stones ordinarily used by the carpenter are quarried in Yorkshire, and are called by the generic name of grit-stones. There are, however, many other localities which produce them, notably Staffordshire, which supplies a quality, called Bilston grit, of a harder and closer texture than those of Yorkshire. The cutting powers of all these depend upon the particles of silica contained in their substance in union with the softer sandstone. The greater the proportion of silica, and the closer its particles, the harder and finer is the stone, so that a selection is generally made by the workman to suit his special requirements. The stone is got out in solid blocks, which are cut by chisels into cylinders of greater or less diameter, and of varying lengths. Around these at intervals deep grooves are cut, marking the several stones ultimately required, and into these are driven wedges of wood—generally willow, which bears a good deal of hammering, as boys used to cricket-bats ought to know. These are driven tightly into the grooves, and the whole is left exposed to the dews of night, which swell the wedges, and the several sections are in this way split asunder without further treatment. The rough surfaces are, however, subsequently worked to a more accurate face with the mallet and chisel, by which the square hole to receive the iron axle is also cut. The largest stones, made to revolve at a terrific speed, are used by the Sheffield cutlers for grinding large pit-saws and other tools, and also by stove and grate manufacturers and others for brightening their iron and steel work. When too small for this purpose, a bar of iron is held against them as they revolve, so as to cut a deep groove, and by means of wedges or chisels they are split into narrower or thinner sections, and handed over to the grinders of razors, scissors, and smaller articles.

Our young friends having to face up the stone which they had trimmed to a correct shape in the way already described, so as to give it a face sufficiently smooth for use, I was able to give them a "wrinkle" which they were not likely to have discovered for themselves. I shall, however, state their difficulties and experiments in the words of the manuscript from which I have already quoted largely.

"It did not take us very long to heat the old and bent handle, which from bad usage and exposure had become rusty and out of form, and to correct its shape ready for use, but it took us a good deal of manœuvring to wedge it centrally in the square hole of the stone. After some time, however, we arranged it to our satisfaction, our carpenter's square assisting us very materially in getting it accurately fixed at right angles to the sides of the stone.

"Our workshop having an earthen floor, we mounted our grindstone upon two posts driven into the ground, driving two staples to keep it in place—a very primitive method, which we subsequently altered to a better; but it served our purpose for a long time, as it had no doubt served that of many others previously. Driving two other posts as a support, we placed a home-made water-trough underneath it, which we could easily remove; and we also arranged a support for the tools, and to enable us to turn up and true the face of the stone.

"For the latter purpose we begged an old file from a friendly blacksmith, selecting the hardest tool we could think of wherewith to attack our friend, who had already proved to us that it was 'rale grit,' as the Yankees say, during our preliminary operations upon its substance. Although, however, we worked very patiently at our task, the file seemed to get by far the worst of it; and although we turned it over and over as the edges in turn became blunted, we did not appear to make much progress in our work.

"Whilst, however, we were thus engaged, our kind friend the surgeon who attended the school, and who had been called upon on one occasion to dress a very severe cut of my brother's, paid us a visit. After watching us a few minutes, he proposed to take a turn at the work himself, and rejecting the file, he picked up a bit of small iron rod that lay near, and to our surprise began to cut the stone at a far quicker rate than we had done with the hard steel, and very soon reduced it to a true cylinder."

This is worth recording for the reader's benefit, as no good work can be done on an untrue grindstone; and the moment it is found to approach such a condition, it must be corrected or it will get rapidly worse. The reason for its untruth is sometimes that the stone is softer in one part than another; but very often it is the result of allowing it to remain partly sunk in the water in the trough, which renders that part more easy of abrasion in use than that which has been kept dry. The weight of the cranked handle always causes the stone to stop in the same position, so that the same part is invariably exposed to this deterioration and is never completely dry. The water-trough should therefore always be so arranged that it can be either lowered or wholly removed when the stone is not in use; a still better plan, perhaps, is to have a drip-can with a tap above it, and to allow the water that runs from it upon the stone into the trough below to escape from the latter at once into a bucket. Our young friends learned all this in due time, but would have saved themselves many an hour's work in truing up their grindstone, if they had been told this and other trade secrets at the commencement of their mechanical career.

The reason that soft iron will answer for the purpose named better than steel, is supposed to be that it contains less carbon, and does not heat so quickly during the operation. It is at any rate a proved fact, and the best tool to use is a bit of small rod to turn down the stone, followed by a bit of hoop iron to give the finishing touch to the surface. The iron must be held firmly on a rest fitted for the purpose, pointing downwards, and the bar must be turned over and over as the upper edge gets blunted. It is at best a somewhat tedious operation, but absolutely necessary if the stone does not run truly; and the only way to lighten the task is never to allow of any irregularity, but to correct at once the slightest tendency to eccentricity.

We soon found, says the narrative, the benefit of the hints given us by our good-natured friend, and henceforward we always kept a rod of iron and a bit of hoop on purpose for this work. Moreover, we learned to save the face of the stone by traversing the tool to and fro across it when grinding it, especially if it were narrow or pointed. The gouges gave us most trouble, but we eventually found it better to lay these *across* the stone, rolling them over and back again as the work proceeded, instead of holding them in the position of chisels and similar tools. Channels and grooves in the grindstone were, however, among the list of finable offences, and until we got well used to the work, our money-box got thereby many an odd copper added to its treasures.

Another secret of tool-grinding was explained to us on a subsequent visit of our friend, who found us at work with the stone running *from* instead of *towards* us. It had appeared to us in our ignorance that this must of necessity be the right mode of grinding, because we fancied that if the stone were made to run as it were against the edge of the tool, it would blunt instead of sharpening it. We had, however, always noticed that a wire edge or thin flexible filament of the steel formed whenever we used the grindstone, which we had to get rid of by drawing it across a bit of wood before we could produce a keen edge upon the oilstone; and sometimes this would also form a second time upon the surface of the latter, which then needed to be wiped and cleaned before we could go on with our sharpening.

Our friend, however, told us that this wire edge was but the result of our mode of grinding, the stone tearing away the steel when it got very thin, whereas if we turned it towards the edge, the particles would be driven inwards towards the solid metal, and as it were compressed. This we found to be really the case, and thus we made a step forward towards a workman-like mode of grinding our tools, and gradually learned the art of producing upon them a good and evenly-levelled edge.

It must not, however, be supposed that the subsequent operation of setting them on the oilstone was acquired without a long series of failures; for at first we rather blunted than sharpened them, and for any special work were only too glad to call in the aid of the village carpenter

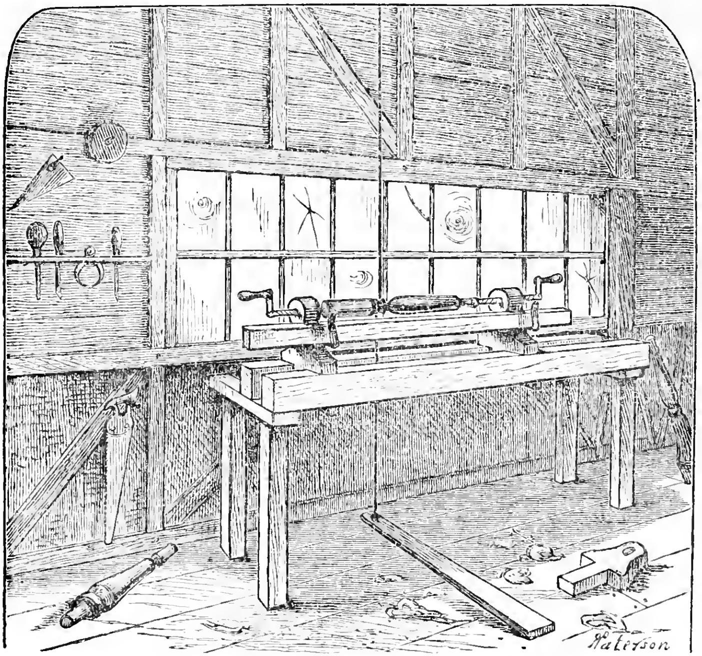

Fig. 1.—Our First Lathe.

or his apprentice to put our planes and chisels in working order. After long and careful practice, however, we triumphed over this difficulty, as we did over others of a more serious character.

Our great ambition was to possess a lathe, which we intended to stand under the window at the farthest end of the workshop. There were not at that period the same chances that subsequently existed of obtaining articles of this kind; there were, indeed, a few firms in London ready and willing to supply them, but only at such a price as there was no chance of our being able to afford for many a long year. No "English Mechanic" or "Bazaar" or other periodical existed whose columns might offer to us a second-hand tool, and it became evident to us that we must contrive to make a lathe ourselves with such appliances as we could muster, and with the help of the blacksmith or old Tim.

The only advantage we had was the power of inspecting two lathes possessed by a chairmaker and by the carpenter. The former was what is called a pole-lathe, a very simple affair, but in the hands of Bill Birch the owner capable of a great deal of good work.

The rough sketch given in fig. 1 will sufficiently explain its construction as arranged in our own workshop, for it was this lathe which we ultimately decided to make, postponing to a future day the construction of a more serviceable one, after the pattern of Bob Chip's the carpenter. It will be seen that the bed of this lathe consisted of a pair of beams placed parallel to each other, and resting upon a frame at each end. We planed the upper surface of these as well as we could, and the front of the foremost one for appearance' sake, leaving the rest rough. As the pieces were of beech, this was to us boys a formidable undertaking. We quickly discovered that beech was far more difficult to face up than deal, to which we had hitherto been accustomed. Our long or "jack plane" sufficed to take off the rougher outside of the wood, but the grain did not run straight from end to end, but seemed to delight in curls and knots, which defied our efforts to reduce them to a smooth surface.

But here again our medical friend came to the rescue and showed us how to conquer the enemy. He pointed out to us that the mouth of our jack-plane being worn was too wide, and that the second iron, called the break-iron, which was fixed upon the cutting iron of the plane, was too far from the edge of the latter. To plane knotty wood, he explained to us that the mouth of a plane should be very narrow, the break-iron not more than one-sixteenth of an inch from the level of the cutting edge, and the latter set very fine—*i.e.*, only allowed to project a very minute detance beyond the sole. With a plane thus arranged very thin shavings are taken, which are fairly cut, and not split off from the surface of the wood; but it is also necessary to work the plane in all directions where the grain is curly and uneven, so as to cause it to cut them lengthwise instead of across. After the surface has been levelled with such a plane, called a trying-plane, it is often necessary to go over it again with a smoothing-plane, which is a very short one, carefully sharpened and set, as it is easier to work this in various directions than it is to do so with a longer plane. The latter, however, insures a more truly level surface.

On or rather between the pieces forming the bed we placed a pair of poppits, of which a spare one is seen upon the floor, showing, more accurately than those above, the tenoned part, with the mortise-hole by which they were secured in any desired position by wedges underneath the bed. Through each of these was a pointed screw, turned up to form a winch-handle by which to move it, and advance or withdraw the point. Between these was mounted the wood to be turned. Through a hole about half-way up the poppits a square iron rod passed, which was bent to form a hook, and upon these rested a long board of beech to support the tools during the operation of turning. The upper edge of this was level with the centre-points, and we could push in or draw out the hooks according to the size of our work. We afterwards found that this board troubled us by falling forward when in use, so we bored a hole in each poppit with an auger above that through which the hooked irons passed, and fitted in these a couple of bed-screws, which we got for fourpence; and by screwing them to bear on the inside of the board, we kept it firmly pressed against the hooks and made it very steady.

The next consideration was the treadle and its fittings The treadle itself was only a board an inch thick, under which, at the part resting on the floor, we fixed two short spikes to prevent it slipping about when in use. From the farthest end a cord ascended, taking a turn round the work, and was fastened to the end of a strong ash pole, of which one end was fixed to the beams overhead, and the other was arranged to come over any part of the lathe. This we managed by putting a round pin through the pole about eighteen inches from its larger end, and driving this pin into a convenient beam, thus allowing the pole a horizontal motion on the pin. Then we nailed a stout bar just over the end of the pole, under which it was free to move, but which held it down securely against the tendency to rise from the strain of the cord at the other end. This pole, therefore, formed a strong spring, which raised the treadle off the floor when the pressure of the foot was relaxed, but yielded to that pressure when the treadle was pressed downwards. During the latter motion the cord caused the work to rotate several times *towards* the workman, so that a tool held against it would cut it freely, but as the pole sprang upward again this motion was reversed, and during that time the tool had to be withdrawn slightly, so as to clear the work.

Many an hour had we watched the old chairmaker turning at a lathe like this, and he certainly worked very fast, and with apparent ease; but it must be confessed that for some time we could do very little, for the rough pieces of wood caused the tools to hop about upon the bar which formed the rest, and we could not manage to advance and withdraw it at exactly the proper moment, so that our work was done but slowly, and was at best very rough.

Soon after we had finished this somewhat unique piece of machinery, our friend the surgeon paid us a visit, and gave us a very interesting account of the way in which turned work is managed by the natives of India, and also by the Africans and others. I give the account in his own words as nearly as I can recollect them.

"Soon after my arrival in India, where I was to act as an army surgeon, I had occasion for several turned articles; for though I had practised carpentry, I had never tried my hand at the lathe. I wanted some legs to complete a small table, and some rounds for a chair back; a leg of my pocket camp-stool was also broken, and needed to be replaced by a new one. At first I proposed to round my pieces as well as I could with a spokeshave, as I had no idea where to obtain turned ones; but Captain Fellows, an old friend, seeing me thus employed, suggested sending for a turner, who, he told me, would do all I wanted for a sum amounting in English money to fourpence. 'But, my dear fellow,' I replied, 'I have no lathe, and there is not one, I believe, in the place; so that it is no use to send for the turner, even if such could be found amongst these woolly-headed black-skins.' 'Wait a bit,' he replied, 'and you'll soon have lathe and workman too;' and addressing a few words in Hindostanee to one of his native servants, the fellow salaamed and hastened off.

"Returning in about twenty minutes, he was accompanied by a native carrying a small adze in one hand, and a bag of matting in the other, containing all requisites, as I soon found, for his work. Taking a couple of long wooden tent-pegs, he bored a hole through each with a native drill in a few seconds, and drove into them a couple of pointed nails or spikes. He then with a mallet hammered them a short distance apart into the ground, placing them just so far asunder as the length of the table leg he proposed to turn. The pegs stuck out of the ground perhaps nine inches. These were the poppits, and the solid ground, which was dry and hard, as it generally is in hot countries, was the lathe-bed. Two more tent-pegs were driven, and a straight-edged board nailed to them at the proper height to form the rest, and the lathe was so far complete, the whole having been arranged within ten or twelve minutes. I had seen a pole or chairmaker's lathe similar to that which you boys have now made, but I was sorely puzzled how the spring pole could be fixed, as there were not only no workshop beams overhead—the roof of the shop being the clear sky above—but no overhanging tree to which a spring of any kind could be fixed. The mystery was presently solved. A strip of raw hide was the cord, which was passed round the work, and the ends given to two natives, who sat on the ground, one in front and one behind the lathe. Each of these pulled alternately, and set the work in rapid rotation, singing a sort of monotonous chant the while, which had the effect of keeping time. It was a regular case of 'Seesaw, Margery Daw;' and I was told that the natives will continue this apparently back-aching work all day without complaint. As soon as the work had made a few revolutions, the pointed spikes were driven into the ends a little farther to render it more secure, and a little grease was added to prevent undue wear, and make the wood revolve easily. The turner then took up his tools, which were of a very rough description, and no English workman could have done better work, or done it more rapidly. In a few minutes the rough wood was shaped to its intended form, measured in length and size from time to time with a bit of Indian grass, and finally polished with a bit of some kind of native rush or reed, like what is known to turners as Dutch rush. When several pieces were needed of the same size and length, they were all roughed over by the hand adze, or *bassoolah*, before any one of them was put in the lathe to be turned; and nothing surprised me more as a new-comer than the skill with which this heavy but keen-edged tool was wielded by the native workmen. It appeared to me that they could do any sort of work with it, heavy or light, from roughing out the stem of a pipe to trimming the timbers of a ship. All natives sit on the ground upon or between their heels, in what to us would be a most uncomfortable position, and they hold the work or the tools partly by means of the great toe, which, never having been confined in hard leather boots, is as pliable and useful as the fingers. If a native drops a tool, he will generally pick it up with his foot—an action peculiarly ridiculous and grotesque to unaccustomed spectators. I have even heard that a native tailor can hold his needle in one foot, and thread it with the other, and from what I have myself seen I am disposed to believe the report.

" In describing the formation of a native Indian lathe, I spoke of *drilling* the holes for the two pointed screws. The Indian and Eastern carpenters never use gimlets, as we do, but a home-made and very effective drill, with which they bore holes with great rapidity, and without any fear of splitting the wood.

" The drill is made almost wholly of hard wood, and in two parts, of which the upper is held in the hand, while the lower is made to rotate by means of a drill bow, similar in principle to those used in England by watch-makers and others. The bow is made of one of the native hard woods of a springy character. I saw one of these drills constructed on one occasion as follows :—

"A bit of wood was selected about a foot long, which was turned in the lathe, smooth and rounded off at the end intended for the handle, but with a few grooves at or about the middle of its length, below which it was made cylindrical. This was sawn across to divide it into two pieces, of which the shortest was to form the handle, the rest the body of the drill-stock. At each end of the latter a hole was bored, one for holding the actual drill, the other for a spindle of very hard wood, which was driven firmly into it, and I believe secured by some native glue or cement. This pivot was like a large-headed pin, the head being made as round and smooth as a small marble, and the shank nicely rounded. This I did not see made, but I should say it was done in the lathe, as it was very nicely formed, and could hardly have been accomplished by hand alone. This part had to be fitted accurately into the head-piece or handle in which it was to work, and the cavity to receive it was made as follows :—

"First, a hole was drilled in the centre of the piece, the size of the neck of the hardwood spindle, and then the whole piece was carefully sawn down lengthwise, so that half of this hole was in each. The distance from the end of the spindle to the knot was then measured, and a cavity for the latter was made with a gouge—half in each piece—and these cavities were made as smooth as possible, so that they resembled the two halves of a bullet mould. A hole was then drilled in one of these pieces to form an oil-hole sloping downwards into the cavity; after which the spindle was put in its place, and the two halves of the handle tied together with Indian grass, to see whether the work was sufficiently accurate. At first it appeared that the lower part had too much play, but a tap on the end, by driving the spindle a little farther into the lower part, brought the ends of the two parts closely together, after which there was no undue freedom of motion, and the fit was perfect.

"Before untying the grass bands which kept the two halves of the handle together, two holes were drilled for rivets, which were of stout brass wire, and when these were in place and headed up, the ties were removed, and the drill-stock nearly completed. The hole at the bottom, however, to receive the drills, was ingeniously 'bushed' with a bit of bone or ivory, into which a somewhat smaller hole was made, tapering to receive the end of the bits of wire out of which the drills were formed. These, in the present case, were apparently made of some umbrella ribs picked up in camp, as they were of a small size; and these steel ribs sufficed well enough for the purpose. They were merely broken off, heated, and flattened upon a stone anvil, and then ground into the required shape by help of a bit of whetstone or native hone, upon which also the other end was slightly tapered to fit the hole in the drill-stock. Some of the larger drills are squared at the end like the "bits" of our own carpenters, and then the hole in the stock is first drilled and afterwards burnt out square with an old nail or other implement. For the natives never find fault with their tools," added our friend, "as small boys are wont to do; but they make good use of all sorts of odds and ends of iron and steel, from the rusty hoop of a barrel to the broken blade of a knife. In fact, nothing in the way of metal comes amiss to them, but their natural ingenuity and acquired dexterity of hand enable them to turn to practical use various broken articles which we ourselves would most probably consign to the dust-heap as absolutely worthless."

Naturally enough, after hearing this account, we became far more sanguine about our own lathe; for, we argued, if those nigger fellows can do good work with their rough-and-ready contrivances, we can do the same with ours, which is, at any rate, one degree better, because we don't want two people to work it besides the turner. Moreover, nothing would now content us but an Indian drill-stock, which we determined to make for our own use, although we were, at the same time, perfectly well aware that, with the same principle of construction, much more efficient tools could be and were actually made and sold at the shops. Our kind instructor nevertheless encouraged and personally assisted us in the accomplishment of our task; because, he said, it would give us the opportunity not only of putting our lathe to some use, but also of exercising our patience and skill in the production of work which needed accuracy. We therefore tried our best, and succeeded, but not until one or two failures had been incurred, the first arising from our having sawn the stock across not quite at right angles to its length, so that the ends would not work accurately together. We had consequently to turn another; and this time, by our friend's advice, we made a mark round it with the chisel while in the lathe as a guide for the saw, and another a little way on each side of the first, so that, if we should fail to cut exactly on the line at first trial, we could still saw off each piece again at the other marks, and thus stand another chance of success.

Our first attempt, however, this time proved satisfactory, and we completed our drilling apparatus very much to our satisfaction. We also found the tool an exceedingly useful one, and frequently preferred it to any other. For holes in thin stuff, which hitherto we had split at divers times with our ordinary gimlets, we always used our Indian drill-stock; and we found that for hard wood, which it was a difficult task to bore with a gimlet at all, the drill was exactly the tool required. We used it with a sixpenny bow of lancewood, fitted with a bit of catgut clock-line as a string; for we found a hempen cord would not stand the work, as it quickly frayed and broke. The greatest difficulty we had to contend with in the manufacture of this drill-stock was the spindle and knob. We tried boxwood and ebony, and one or two other kinds, but all to no purpose, as they proved too brittle for our requirement, unless we made the spindle much larger than was otherwise necessary. At last, however, we got hold of a bit of ironwood, and by dint of rasp and file—for we had no tool that would cut it—we eventually succeeded in giving it the necessary bullet-headed shape. It was nevertheless a long job; and even at last—although when in place it seemed to work very well—the globular head was not, it is to be confessed, of very accurate form. For its bed we got hold of an iron bit


Fig. 2.—Indian Drill-stock.

called "a cherry," and made to fit a carpenter's brace. They can be had at the London tool-shops, and are used, in fact, to recess the cavities of bullet moulds, being made of hard steel, and channelled so as to have many cutting edges.

Our friend kindly lent us a drawing of one of these native drill-stocks, which, however, was lost with some other mechanical sketches.

The writer has had the good fortune to find another recently engraved in the "English Mechanic," and by the editor's permission it is now copied into this little work. This will make its construction quite clear, with the help of the description already given.

CHAPTER II.

OUR WORK.

I MUST now relate what we contrived to accomplish with our imperfect appliances; and it may encourage other boys of mechanical tastes to state that some of our early work is still in existence after the wear and tear of ten or fifteen years, and is almost as serviceable as ever. This, I have no hesitation in saying, would not have been the case had we yielded to the usual temptation to do such things carelessly; but, from the commencement of our career, we determined to act in the spirit of the old proverb which tells us that "what is worth doing is worth doing well."

Our first attempt at regular carpentry was a set of steps for our own use in putting up shelves, and other such jobs as needed longer legs than we were possessed of.

They were not required to be very high, and we had in our possession a board or two of deal an inch thick and nine inches wide, that appeared well suited to our need.

We found, on measuring these, that we could make the side pieces five feet long, which we fancied would result in a set of steps four feet high when placed in the usual sloping position for use. As this was a first attempt, we did not propose to make them with a hinged frame at the back to shut up, but with fixed supports, especially as we could then contrive to put braces to stiffen the whole if there should seem to be any grogginess in their condition.

The first point was to see to the state of our planes. The jack-plane, having been used upon the lathe-bed to take off the rough outside of the beech bearers, was evidently in a very blunt condition, though not damaged by notches, and we had to try our hand at grinding and setting it. This, I think, rather pleased us than otherwise, as it would put our new grindstone to the test. After what our friend had told us about wire-edges, we did not fall into the error of turning the stone away from the work, but we had some difficulty in holding the plane-iron steadily, and preventing it from an occasional dig in, thereby cutting into the stone, and damaging its edge instead of improving it. Being the eldest, I asserted my privilege to be head-carpenter, and Tim, as carpenter's apprentice, had the task of working at the handle. I should not like to say how often he had to change hands, nor how unduly his labours were extended owing to my own inefficiency. First I found that I was grinding the tool more at one corner than the other; then the bevel was rounded instead of being quite flat, as I knew it should be; but at last matters appeared more satisfactory. Trying it with our carpenter's square, we found the edge fairly at right angles to the sides of the iron, and the bevel tolerably flat and even; and glad enough was poor Tim to let go the handle and give his arms a rest.

Then I set about the difficult task of finishing the cutting edge upon the oil-stone. We had bought one of these out of the stock of a bankrupt carpenter, arguing in our minds that we were far more certain in this way to get the genuine article than if we went to a tool-shop; and no doubt we were perfectly right in our supposition. It turned out eventually that we had thus secured not only a real Turkey stone, but one of good cutting powers, and even hardness—qualities of great value and importance, in which, however, many of the Turkey stones fail. Had our boyhood been of later date, we should have found other and cheaper stones in the market, especially Washita oil-stone, which is excellent for carpenter's tools, and Arkansas, also from America, some of which is very fine and hard; but in our day the ones most readily obtainable were Turkey and Chorley Forest oil-stones, both, however, very serviceable, and fit for our purpose. It was with a good deal of anxiety that I set about the job in hand, which indeed looks easy, but requires a good deal of knack and some practice for its proper performance. However, I set to work, and diligently rubbed the iron a few times up and down the stone, as I had seen Bob Chips do with so satisfactory a result. I then stopped to look at the edge, Tim also being at my elbow to assist in criticising the work. Feeling the edge, we both agreed that it was tolerably smooth and sharp, but somehow it did not look exactly right. We had, in fact, rounded off the first-made bevel, instead of making a fresh one on the oil-stone, which gave it what Tim called a *doubtful* look, as if we did not precisely know at what angle we wished to grind it.

We, nevertheless, determined to use it in its present state, lest we should make bad worse in further attempts to improve it. We accordingly put it back into its stock, and set it, after one or two trials, at the right distance below the sole. Although it proved fairly satisfactory in cutting powers, we were very warm, and weary too, before we had finished the broad surfaces of our two boards, and, in addition, we had not exactly satisfied our expectations as to the squareness of the edges to the faces. We had not, as we afterwards learned, gone about the process in the right way; and as other boys may some time or other read of our difficulties and failures, I will here add the proper order of carrying out this work, and squaring up such boards or pieces of wood.

The first process is to level one of the broad faces. The eye alone will not be a sufficient guide in testing the correctness of the planed surface, which must be tried by the edge of a square, or by a straight-edge such as the edge of a carpenter's rule. But it is much more satisfactory, and often absolutely necessary, to have two strips of wood, very truly planed upon their edges, which can be stood upon the board at opposite ends. If the board is "out of winding," *i.e.*, has not a twisted surface, the tops of these straight-edges will coincide, if the eye is brought to a level with them; but if it is otherwise, they will of course *not* agree. The board must be tested in this way as the process of planing it proceeds, moving the straight-edges to various parts of it, and noticing what particular places require to be lowered to reduce the whole surface to a uniform level. Then must be planed one of the edges; and this is where we made the mistake, as we planed first of all the two opposite sides of the board. This first edge must be tried with the square at all points, and, if very narrow, it will prove rather a severe test of a young workman's skill. Even in the case of a board an inch thick, such as that upon which we were operating, much care will be required, and probably some time will be expended before it becomes accurately square to the sides. Then *from this* the third side must be worked, and lastly, the second edge, always testing from the last finished surface. This lesson, however, we had not at the time learnt, and the consequence was, we worked in a hap-hazard way, and our pieces were not very accurately planed. We did not recognise this until we came to fit the steps, when we were somewhat astonished to discover that they required to be forced into place in one part, while in another they fitted too loosely, although we had taken great care to cut them all accurately to the same length. The sides were, in fact, "winding," and, consequently, were not parallel to each other at all points, and the tendency of the steps was to take up a position like those of a winding staircase. To correct this we had to sacrifice closeness of fit between some of the pieces, and to cut others out of square, and this rendered our steps so rickety, that we were obliged to add braces to keep them together, much to our disappointment; for, so far as our knowledge went at the time, we had taken much pains with our work.

After planing the side pieces, as stated, to what we at the time believed true surfaces, we set off the different distances for the steps. This necessarily puzzled us considerably, as we could not think how to mark the places for the ends of the steps, so that when the sides were placed in a slanting position in use, they would be horizontal. Moreover, we saw that the ends of the side pieces must be so cut as to be parallel with the steps. At Tim's suggestion, however, we set up one of these edgewise, leaning it against the wall at about the required slope, and then, while it was in this position, drew by hand a line across it from the top corner, which touched the wall as nearly horizontal as we could, and then laying the board again upon the bench, we made this line true by ruling it. We then took this as our starting-point, and from each end measured equal distances to represent the top of each step, finishing by a similar line to show us where to cut off the bottom piece, so that the steps would have a firm bearing upon the ground. We then sawed it off correctly at each end, and used it as a gauge by which to mark the other side piece. Now we found that if we set our five-feet plank with its *edge* against the wall at the height of four feet from the ground, as we intended it to be when finished, we were working out that well-known mathematical fact, that the square of the base of a right-angled triangle equals the sum of the squares of the two sides which contained the right angle; for when we measured the distance from the wall to the lower corner of our board, we found it to be exactly three feet. The square of five feet we knew to be twenty-five, which was just equal to the square of four feet, or sixteen added to the square of three feet or nine, equalling twenty-five. The base of the triangle was of course the inner edge of the plank which touched the wall and the floor, and was practically only a straight line. After cutting away the triangular pieces at each end, which reduced the board to what we knew was called a rhomboid, we found that we had about four feet five inches to divide equally for the steps. We called it in the rough four feet six, and agreed to put five steps, the upper surfaces of which should be nine inches apart; then there would be the top step of all, nailed to lap over somewhat, and the lowest division—*i.e.*, the space from the last step to the floor—would take up the odd inches, namely, eight, making up the fifty-three which we had altogether at our disposal.

In order to make the above description quite clear, an outline sketch is appended, representing what has been stated above. A is the board leaning against the wall; its upper corner, D, resting at four feet from the floor; and its bottom corner, E, resting upon the floor at a distance of three feet from the wall. The triangular bit E, which had to be cut off, lowered the whole six inches, so that when completed, the steps were just three feet six inches, just six inches shorter than we had proposed, but we could not foresee this as a regular carpenter would have done, and practically it was not of much importance.

Having set off on each edge the position of the upper surface of the steps, and ruled lines from one mark to the other, we made similar lines an inch below each, to mark the thickness of the several steps, and we intended then,

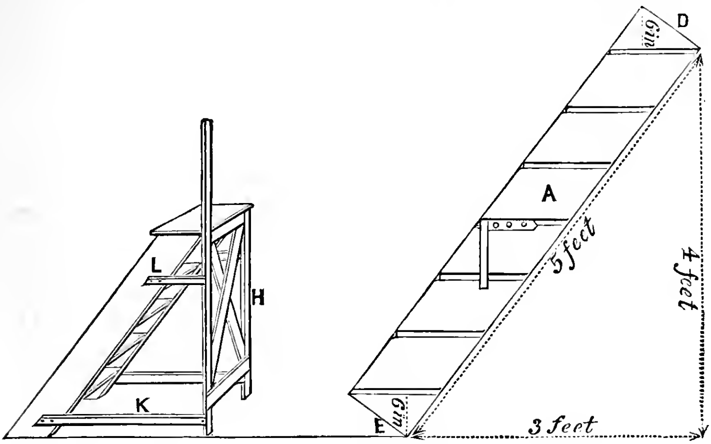

Fig. 3.—Our Steps.

with a tenon saw, to cut a little way into these marks, and with a narrow chisel to remove the intervening wood, so as to let the steps into the sides, as we had seen them in a set made by the carpenter. But we did not want this to show upon the *front* edge, and we therefore, with our square placed as in the figure, set off the end of each groove, which thus ended slightly within the edge of the side pieces. I think a glance at the sketch will render all this perfectly clear, and indeed it is all simple enough, but takes a good many words to describe it accurately. A perspective view of the finished article is also added, in order to show the back and sides.

We made a frame like H of strips two inches wide and three-quarters thick, fitted with tenoned and morticed joints; and here, being forewarned by experience, we were additionally careful to plane up the pieces truly, so that the frame should be flat and not twisted. We left one side higher than the other to form a stay or handle to steady the climber when using it. Having glued and pinned this frame together, we then braced it across with two half-inch strips, nailed on, and notched into each other where they crossed. When finished, we attached it by side strips, KL, to the strips on each side with screws, the heads of which we let in by a countersink.

Thus our set of steps was finished, and when we had painted them stone colour, and also painted our name in black letters, carefully ruled, which we traced first of all from letters on some handbills, our performance was by no means discreditable to young apprentices like ourselves. True, there was a little putty here and there to fill up open places in some of the joints, and the steps required at last a little secret adjustment before they would stand quite steady; but the paint concealed the first, and as to the last, we had little to complain of after finally adjusting the length of the legs; so that this set of home-made steps proved extremely useful, and, to our pride and satisfaction, were actually borrowed on several occasions by the inmates of the schoolhouse. Even the head-master used them sometimes to reach a book from his top shelves, and ultimately gave us an order, to our great delight, for a similar set, for which, I now think, he paid us about double their real value.

We had not as yet done much with our lathe, on which, nevertheless, our ambition chiefly centred. We therefore agreed to set bravely to work to conquer once for all the difficulties we had hitherto met with in its use. I doubt, however, whether we should have done this for a very long time, if we had not succeeded in bribing Bill Birch to give us a few lessons. Nothing, however, would induce him to try our own lathe, or hardly to look at it. "He knew," he said, without examining it, "that it would not answer for real work; but if we could get the Doctor to allow us to come to him the first half-holiday, and would give him half-a-crown to pay for his time and trouble, he would show us how to go to work in the right way."

Although our pockets were not very well lined, we agreed to these rather hard terms, and as a lucky birthday had given us a tip from home, which had not yet gone the way of tips in general, we obtained leave from the Doctor on the ensuing Saturday, and presented ourselves at Bill's workshop, money in hand.

"Well, young gents," said Bill, "I am just going to do a bit of turning, and you can stand by and look on, but don't you be talking unless I speak to you, 'cause that only bothers me and don't help you. But old Bill Birch *can* turn, mind you. Why, lads, before I were your age, I could turn all the parts of a chair, and put it together too; but then d'ye see, Bill had a feyther, and he had a stick, and that stick were a good deal used instead of words in teaching me my trade. 'Twas—'Hulloa, Bill, here's a notch in my chisel!' 'Hulloa, Bill, here's a good chair leg spoilt!' and then down came the stick pretty sharp. So I soon learned to do my work as it ought to be done, and when feyther grew old and rheumatic, he would hobble into the shop and look on, and say, 'Bill Birch, lad, you're a turner, and a rare good 'un too; and lookee here, lad, 'twas thy feyther taught 'ee, and he's proud of 'ee, Bill, he is, for there's not a man this side of Lunnun as can beat 'ee now.' So, young gemmen, you be come to the right shop to larn, only ye'll never turn like old Bill, so ye needn't expect it. There's plenty of talk in these here days, and no taching. Why, I never had but one prentice, and he ran away—he did."

We had heard of this prentice of Bill's before, and, knowing, as we did, that the ash stick had been considered in his case also the only able instructor, we rather applauded the lad, who, to avoid a too frequent application of it, had "made tracks" out of the village, and was now, under a new master, already a very fair hand at the lathe. This latter fact, however, old Bill persistently ignored, and if we asked him (as we often did), where his old apprentice was now, all he would say was, "Ah! *he*'s no good; he should ha' stayed with old Bill, but he run away—*he* did; *he*'s no good." We fancied old Bill would have preferred teaching us lads in his own way too, for he was a grumpy old chap, but the half-crowns and sundry words of flattery and praise of his skill kept him in tolerably good humour.

We soon found, however, that the old man became so busied in his task, that he actually forgot our presence altogether after a few minutes, and was only recalled to a sense of our proximity by a sneeze from Tim, who was nearest to his elbow, and who was consequently imbibing a certain amount of fine dust from a bit of worm-eaten beech which was being converted into the rail of a chair or stool.

Being thus made conscious of the fact that two lads awaited his instructions, old Bill tossed down the now finished rail, settled his spectacles, took a pinch of snuff, and then selected a bit of wood, which was to be submitted to our tender mercies under his directions.

"Now, look ye here, young gemmen," said he. "You've got to make this rail like the one I've just finished, and ye can't do it," he added, as I suppose, by way of encouragement! "Now, first of all, as ye're young hands, ye'd better take a gimlet, and bore a hole at each end for the lathe-points, 'cause ye'll be sure to make the tools catch in; and then, if the centres aren't pretty deep, out comes the bit of wood, and maybe ye gets a rap in the face at the same time. Why, lads, I've seen a lathe with a strong ash pole overhead fling a bit of wood right across the shop and through the window; ay! and I seed one chap knocked over, with his eye bunged up for a week after. So, as I said, ye'd better bore a hole at each end like this. And now ye see, nothing's easier than to put it in the lathe, and screw up the points pretty tight; only, ye see, I just take a turn of the cord round it first; and this cord, mind, is a bit of raw horse's hide, nothing but raw hide properly dressed, as old Bill knows how, will stand the work. And, mind," he continued, "that you give the turn in the right direction, so that when you press down the treadle, the work shall run towards you, because then you'll get into the way of putting the tool forward into cut at the very same moment that you press down your foot.

After a bit ye won't need to think about it, but it'll all come as nat'ral as spiders catch flies; and there's a pretty many spiders up and about this here shop, and I expects they knows old Bill won't hurt 'em, and maybe they like the sound of the lathe too, but that's neither here nor there, only there's hundreds of 'em under the old thatch up there."

All this time the old man kept running the wood backwards and forwards while lightly grasped in his right hand, and was evidently relapsing into a state of forgetfulness about the proposed lesson. I therefore ventured to remark upon the accuracy with which the wood was centred, and also to suggest that I supposed he always began work with a gouge. "There, there! I told ye not to talk," was the answer. "Gouge, of course, before chisel; but bless ye, lad, ye won't want no chisel yet a bit. Here," he added, to my great joy, "you catch hold of this here gouge, and let's see what ye can do." Taking up the tool at his bidding, and at the same time putting my foot on the treadle, I was just going to begin, but in a nervous sort of way, when Bill roared out, "Not so, lad—not so, that won't do. Grip the tool by the handle in the right hand, and seize it with the left close to the rest, and hold on like grim death. And don't hold it so level" (horizontally), "but slope the point upwards. Don't ye see, if you hold it level, all the rough parts of the wood, as they come against the edge, only hammer it, and, sooner or later, knock out a very pretty lot of notches, 'cause, ye see, 'tis but thin stuff at best, and good steel is very brittle. But if you hold it pointing upwards, the edge will cut the chips clean off, as it ought to do." We both saw at once that old Bill was right, and that, like most beginners, we had held the gouge so that it could only scrape, and we now perceived how it had happened that we notched and blunted our own tools so frequently.

With a pole-lathe, we found it impossible to run the tool along the rest as the work revolved, although we managed this at a later period. For the present, we had to be content with reducing it by a series of separate grooves to the required size, running these into one another, however, as well as we could afterwards. For final smoothing, we had to let Bill himself go over it with a chisel, for our attempts to use this tool were decided failures. First one point caught in, and then the other; and we could (as Bill had forewarned us) do nothing with it. Still an hour's steady perseverance was not without its effect, and so well pleased was old Bill with our determined and zealous attempts to get over our difficulties, that before we left, he condescended not only again to put the turning chisel into our hands, but to give us the following accurate instructions for using it.

"You see, lads, the chisel is not like old Bob Chips's the carpenter's, but is ground off sloping, so that it has one very sharp point and one blunt; and Chips's is only ground from one side, while this is ground on both, so that the edge is in the middle of the tool. And, you see," he continued, "we grind very long flats or bevels, and gets 'em as true and level as we can; and then, just a rub on the stone *on both sides*, and the tool is ready. Then," he continued, "we lays the tool so as to rest almost flat against the bit of wood, but at the same time keeping the upper point quite clear of it. This, ye see, is the secret. The lower point—and ye may put either the sharp or the blunt one below—can't catch in, but if ye only let the upper one touch the wood, in it goes as sure as them spiders eats flies, and then ye ploughs as pretty a furrow as old Tom Wurzel ever made in his life, and your work is spoilt right off, and most likely the point" (or *pint*, as he called it) "of the chisel is left sticking fast in the wood, and then there's a pretty long job at the grindstone."

We had now to bid farewell to our instructor, but we had really gained a good deal of instruction, which we could at our leisure put in practice at our own workshop. Indeed, we found that, after clearly understanding the principles of the art, and the mode of using the two most important tools, we had to encounter comparatively few difficulties, and these were due simply to our present lack of manual dexterity, which further practice supplied. As to our own lathe, we found, in spite of old Bill's contempt, that it was practically almost as good a tool as his own. We had made it very firm by driving the upright timbers into the solid ground, and nailing the others to the beams of our workshop. We found, indeed, that these timbers of the old shed were of great value to us in fixing our bench and shelves and a tail vice, which we picked up at an old iron store, and similar workshop necessaries; and although we both lived to occupy premises of far handsomer and more pretentious appearance, we never found any workshop more fit for the purposes of the carpenter and turner than that dear old shed at Brampton. A photograph of it, both of its exterior and interior, with our primitive lathe and apparatus, hangs now in our study.

From first to last the chisel gave us the most trouble; for although, after some practice, we avoided lowering the upper point so as to allow it to catch in, we could not succeed in giving a perfectly level surface to the work. On the whole, we found it easier to work with the sharpest angle below; but old Bill never seemed to care much which was uppermost. He would lay the tool flat upon the work, and run it along with one hand, and use it with equal facility from right to left or the contrary way. We, however, found that it was more difficult to use it running from left to right, and only persevering determination to succeed gave us the victory at last.

When, however, in after years, we were enabled to discard the pole-lathe in favour of a better, we found ample cause to rejoice that this inefficient machine had given us our first lessons in the art, for it had afforded us a great deal more practice of the right kind than usually falls to the lot of amateurs. The gouge and chisel are *par excellence* the tools of the wood-turner, but their use is generally considerably neglected by those who can afford expensive lathes fitted with a slide-rest. This article is made to serve instead of skilful handling of the more ordinary tools, and the gouge proper, with its ally the chisel, only appear in the form of short bits of steel fitted into a holder, and run to and fro by means of the slide-rest screw—an operation which demands no skill on the part of the turner, but which renders the surface of the work absolutely true.

Lads who are fond of mechanical work should make up their minds not to resort to these byeways of the turner's art, but learn to do all that is possible with simple tools, and only fall back upon these mechanical aids under the pressure of necessity.

After we had attained what at any rate appeared to ourselves a fair amount of skill in turning such small pieces as are used by the chair-makers, that is to say, chair rails, legs of tables, tool handles, and such-like articles of comparatively small diameter, our ambition centred on a bread platter. We had not before attempted anything of the kind, and we did not see how it would be possible to arrange the cord, even if we began by sawing out a piece of board, and rounding it off before putting it in the lathe. We rather doubted, in fact, whether our friend Bill could manage an article of this kind; but on passing his window one day, we saw three platters exposed for sale, besides circular stands for tea-urns, lamps, and such-like, and also, in addition to these, a stand of rather pretentious character, fitted with an inverted bell-glass for an aquarium. It was evident, therefore, that articles of this nature were within the scope of the pole-lathe.

We at last told Bill of our dilemma, but the old fellow would not help us. All we got for the present by way of reply was, "Turn platters in a pole lathe! o' course ye can, if ye know how, and can handle the tools; old Bill turns scores of 'em, but *he* can turn, *he* can."

Determined not to be beat, we set our wits to work again, with the following result. We first of all trimmed a piece like a large, very large cotton reel, but short in proportion to its size. We took care to make it as true as possible at each flange or end, where it was about three inches in diameter. This we set on one side. We then cut out with a keyhole saw, for want of a compass saw, a round bit of sycamore previously planed on both sides to three-quarters of an inch thick, its diameter in the rough being ten inches. We made one mistake in our work, which we record for the reader's benefit. In our undue haste to get our bit of wood into shape, we cut it out before we had planed it. The result was greatly increased difficulty in performing the latter operation. It was well enough so far as the central line—the parts immediately about its diameter—were concerned; but when we tried to plane on each side farther from the centre, the wood insisted on revolving the moment the plane began to cut. We only succeeded by sawing a wide notch in a bit of half-inch board laid against the planing stop, which, by embracing, as it did, a good part of the circumference, kept the work steady.

After this experience we avoided the difficulty in future by planing the board before cutting out of it the circular piece required.

We had marked out the circle with a large pair of compasses, and from the same centre we marked also a three-inch circle. We now took our big reel, and glued it carefully down upon this part, and further secured it by two short screws, which passed through the flange, and reached a quarter or three-eighths of an inch into the board, as we rightly conjectured that we could easily fill up and conceal such holes after the work was finished.

When the whole was dry, we mounted it in the lathe. We found the impetus, however, much greater than we had expected, and every time the rotation was checked before it commenced in the opposite direction, there was a sudden jerk which seemed to threaten to throw the concern out of the lathe—probably to the detriment of the turner's nose.

But steady determination will do wonders, and although we had not yet ventured to apply a gouge to the work, we found that, by turning more slowly, and slightly easing the foot at the end of the up and down motion, we could in a great measure diminish the impetus and reduce the danger.

The first application of the tool brought the work to a standstill, and buried the point of the gouge somewhat deeply in the wood. Luckily, however, it did not take out a piece of the edge, nor did it remove a chip. We now found that it was a very different and far more difficult matter to turn an article of this kind than a simple bar or tool handle, and that it was necessary to place the rest as close to the work as it would go without touching it, and to make very slight cuts indeed. We also learnt another fact, namely, that it was much harder work for the leg, because a bit of wood of large diameter represented a lever equal in length to the radius, which, as soon as the tool was applied, became a resisting power, which we had to overcome. But this fact we had impressed on our minds more thoroughly after our pole-lathe had been replaced by one of the more generally known form, in which the work is driven through the medium of a fly-wheel. In the pole-lathe, the power of the foot acting directly upon the work gives an advantage which the other lathes do not possess, and the whole weight of the body being thrown, when necessary, upon the treadle, gives the turner very great power in causing the work to rotate against the tool. There is, of course, the spring of the pole to be overcome, but this is not so great as would be supposed, and does not add very greatly to the labour. When this class of lathe was more general than it is now, the pole was sometimes replaced by a bow of lancewood or yew, or other elastic wood, which was strung exactly like that used by archers, and from the middle of its string descended the cord to the treadle. This was, however, more general on the Continent than in England; and in an old French work by Plumier, which has become very scarce, there are drawings of these lathes, with steel spring bows mounted on an upright pedestal fixed to the lathe itself; and the latter was not the clumsy contrivance of the old chairmaker, but fitted very cleverly, and capable of being applied to the general purposes of the watch and clock maker, and to that of the general turner.

The pole-lathe is certainly becoming a thing of the past, being mostly superseded by its more elegant and more serviceable brother, but it is still employed by preference for certain purposes. In the soft-wood districts, where wooden spoons are made, it still has a place in the workshop; and I was told by a turner that it is preferred on account of the ease and rapidity with which such work can be mounted—no chuck being needed. Nevertheless, I have seen a steam-power lathe of the usual construction used for a similar purpose; and although the mandrel must have revolved two thousand times in a minute, I saw a lad mount his work, and remove it when finished, without even stopping the lathe. Moreover, I am inclined to think that even old cantankerous Bill Birch, if he had seen the dexterity with which the lad in question used gouge and chisel, would have been obliged to confess that one other person besides himself could turn.

It is not necessary to tell the reader all the further particulars of our work on that wondrous specimen of the turner's art, the bread platter. We succeeded, by careful manipulation, in bevelling off the edge and producing something like a decent moulding round it; and by dint of tolerably free application of glass paper, we put a sufficient finish upon it to satisfy our youthful aspirations. To detach the reel from the back, and, by a little rubbing with a tool handle, erase the marks of the screws, and clear off all trace of the glue, was not a very difficult or prolonged task, and we then determined to go over to old Bill the following Saturday, and to submit to his critical eye this specimen of his pupils' handiwork.

To obtain permission to do this was not a matter of difficulty. We never abused the liberty which the Doctor gave us, and therefore it was extended to us freely at all times, when it did not interfere with the school-work, to which we continued to apply ourselves as steadily as we could. In fact, we considered it a point of honour to study hard, and it soon grew into a real pleasure. Our mathematical work especially gave us an interest which we did not feel equally in the classical, as it enabled us to understand, to a great extent, the principles of machinery as well as of mechanical work, and we were often pleasantly surprised to find that we were but carrying out in the workshop principles which we had been learning in our school hours, and that the more closely we studied these principles, and the more carefully we worked out the problems given us, the more clearly we understood the why and wherefore of many details of practical mechanics. It was thus we were led to perceive the reason that works of large diameter required more labour than those of a smaller size, that the latter gained less impetus as it revolved, and that its motion could be suddenly arrested without much difficulty, and without producing any great shock; that the smaller the work, the greater might be the rapidity of rotation; and why, on one memorable occasion, so severe a blow was given by a piece of wood which suddenly escaped from the lathe-centres when at full speed. These mechanical laws, as we gained more and more sound information respecting them, interested us very deeply, and gave great zest to our self-imposed labours.

When we presented ourselves at Bill's workshop, platter in hand, we saw a shade of disappointment overspread his features. Pushing up his spectacles into the roots of his hair, he deliberately and closely examined our work; then pulling down the glasses again, and settling them comfortably on his nose, he laid down the platter on the lathe-bed and resumed his work. We could not help feeling highly amused at his evident perplexity. He did not expect, nor intend us to succeed, without receiving a special lesson, and for this lesson he had reckoned on another coin out of our pockets. For Bill was a grasping, close-fisted, and churlish old fellow as ever held a gouge, envious of his fellow-craftsmen, whose work he delighted to depreciate, and a regular tyrant in his own house. But no equally clever hand was within our reach, the nearest craftsman living out beyond St. Ives. We knew that we should best propitiate Bill by depreciating our performance, and expressing our regret that he had not been at our elbow when we were at work. Tim was a greater favourite than I was, being a better hand at this sort of (perhaps pardonable) humbug; he therefore commenced the assault.

"I wish we could turn like you, Bill," said he. "I thought we should never get through this job, and I dare say you could have done it in five minutes, and somehow, now it is done, the platter doesn't look like a workman's. Any one could tell it was a boy's work, eh, Bill?"

"Boy's work!" answered Bill, "tisn't work at all; you might cut out a better one with a pocket-knife."

We knew that was an exaggeration, but said nothing; and Bill resumed.

"Look here now—where's all the sharp, clean-cut work ye see in Bill's platters? This here one isn't cut at all; 'tis just muddled and rubbed into shape with sandpaper; and this here edge you calls a moulding ain't no sort of form. All that is tidy about it is the planed part, and that is half spoilt too by the sandpaper."

Then Bill began another bit of work, and was silent till he had finished it, which took him about three minutes, after which he suddenly asked, "How did ye do it?"

We knew now that the ice was thawed, and began to enter into a detailed account of how we had made the big reel, and glued it on for the cord to work upon, and what difficulties we found in turning up the edge, not omitting to repeat the fact of our regret at not having had Bill's assistance.

Thus further mollified, the old fellow condescended to converse more freely, especially when Tim pulled out a packet of snuff, of which Bill was insatiably fond, and presented it to him. I can't say, however, that he evinced any gratitude for the present—he never did—nor do I think there was a spark of gratitude ever present under that gaudy but faded old waistcoat, which had been bought cheap at a pawnbroker's. The snuff, however, had an effect, as we soon perceived. Taking out of a cupboard near the lathe a bit of wood cut out with a sweep saw and nicely planed, Bill proceeded to mount it in the lathe. For this purpose, however, he did not glue on a bobbin, as we had done, but produced two pieces made thus:—One was like our big reel, only *one* flange was much larger than the other—about six inches diameter, the reel itself between the flanges being about three; and from the larger face projected near its outer edge four sharp but short spikes, being the points of screws driven from behind, and afterwards sharpened with a file. The other bit was merely a round flat piece, also having spikes projecting on one side, and on the opposite side of each was a central hole to receive the lathe-point.

The platter was pinched between these, which were placed on each side accurately by a circle drawn on the wood with compasses, as we had done. Thus, without glueing, these bits of wood served to turn from three to half-a-dozen platters, after which the holes for the centre-points of the lathe became, Bill told us, too much worn to hold the work safely, and the pieces were replaced by new ones. Besides sycamore, Bill used, as we found, willow, plane, and beech, and indeed any tolerably soft wood of even and close grain, any wood not naturally prone to splinter and chip easily. He turned the moulding at the edge chiefly with the gouge, but afterwards, with the sharpest corner of the chisel, he cut out a shallow angular grove, which gave a finish to the work by making a well-defined edge to the moulding. He afterwards showed us a very useful tool for this and similar purposes, viz., a V tool, which was similar to a gouge, except that instead of being round like the half of a tube, it was like a bit of paper folded sharply lengthwise. It was then ground from the outside, and made very keen upon the oil-stone. This tool, we were also graciously informed, was used for cutting screws in soft wood, an art requiring much practice, but which Bill did very well in his old lathe by dint of bringing down the treadle very slowly and following a pencil-line carefully drawn beforehand. This he rightly considered rather a feat, as few turners could do this, or make Elizabethan twist, or roped-work, as it was called, for which we received instructions at a much later date, which will be recorded for the reader's benefit. As to sand or glass paper, Bill warned us never if possible to use it, but to use sharp tools, and use them in a workmanlike manner, because abrasive materials always rubbed off the sharp edges of the work, and gave it a very poor, 'prentice-like appearance. But if at any time such means were absolutely necessary, he told us always to take up a very sharp chisel or V tool, and make a final cut after the sandpapering, to restore the sharp edges which the paper had obliterated.

Before our acquaintance with this queer old fellow commenced, we had read about the chairmaker's pole-lathe, but never could have believed the extent of its capabilities in the hands of a good workman. This is practically the lathe which serves the purpose of the watchmaker, who, with a bow of whalebone strung with a horse-hair, and a graver or other tool held in one hand, turns up the pivots and small wheels upon which he has to exercise his skill. There is, indeed, one advantage in a bow-lathe, viz., its comparative portability. On a small scale it may be made, and *is* made, to clamp in a vice or to screw to a table; and may be made either to work with a bow held in the hand, or, by the addition of an upright pedestal to hold a bow overhead, it may be arranged to work through the medium of a treadle. We made such a lathe in after years, taking a hint from an old French work, and give a sketch of it here, as we used it for many light jobs with very satisfactory results.

It is pretty much like the Swiss turn, or turn bench, but we made certain additions and alterations which we believed to be improvements. In the first place, the flat bar of iron, B, on which the rest of the lathe is fitted, was made thick, and flattened out at one end, M, so that it could be arranged as a clamp; and the jaws of this were outward, so that if clamped to a table on the right-hand corner, the bar would stand clear, so as to allow the cord also to pass down free of the table to a light treadle, a mere strip of board three inches wide. The poppit on the left of the bar was fixed by a couple of screws, the other, which was free to slide on the bar, was clamped by the screw seen below it, as was also the rest-socket, C, into which the upper part, L, fitted, the same screw clamping both. O Q R S is the support of the bow N, and this we made of hollow iron tubing, in pieces fitted together where the lines are seen across it, so that it could be taken to pieces for the sake of portability. As

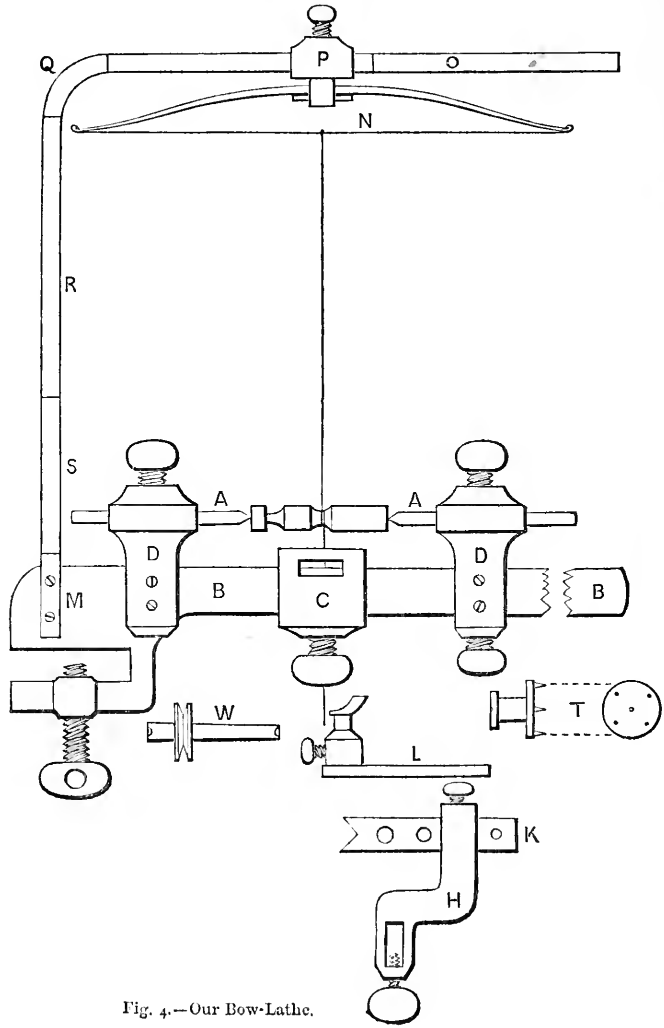

Fig. 4.—Our Bow-Lathe.

we could not manage to fit these with screwed joints, we fitted into every other piece a turned bit of wood, which was tightly driven into the tube, but about two inches of which was left standing outside. This, which was turned very slightly smaller, fitted the other bits of tube, so that the whole fitted together like the joints of a fishing-rod, and were very stiff and firm. Over the horizontal rod O, we made a sliding piece of hard wood to clamp with a screw, and the bow fitted a mortice in the lower part of it, and was then wedged in so as not to slip. At M there was a flattened bit of solid iron screwed to the bar, the top being filed round for the first joint of the tube to slip over it. The central turned spindles, AA, which fitted into the poppits, were pointed at one end, and had conical centre holes at the other, and either or both could be turned end for end at pleasure. The mortice in C, through which the bar B passes, was made higher than those in the poppits, so that it fitted loosely on the upper and lower edges of the bar, but closely on its sides. Thus the screw below could draw it down nearly half an inch, and when the foot of the rest, L, was put through the other mortice, it was easily fixed by the screw in any desired position.

The poppit, K, and its fittings composed our boring collar, which was necessary to hold one end of any bar which required to be hollowed out or bored. The poppit fitted on the bar exactly like the other two, one of which it replaced at pleasure. K was of hard wood, made to fit in a mortice and clamp with a screw, with conical holes in it nicely bored. The exact centres of these we marked by running this poppit close to the other, and giving a slight tap to the centre-point so as to mark it.

T is one of the chucks already described in speaking of the large lathe. Any round flat bit of work was held either by being pressed on the points, and kept against them by the back spindle, or pinched between two such chucks, in which case, the centre-point came against the back of the second chuck instead of against the work itself. W is one of another set of chucks—spindles for holding washers, small wheels, rings, and other such articles; the pullies were made to drive on tightly, the spindles or arbors being slightly conical. Some of the pullies were like that shown for a hand-bow of whalebone, and fine gut or hair; others like a cotton reel, which, in fact, we actually used for the cord from the overhead. These arbors were all of steel drilled at each end, so as to run truly on the points of the spindles. We had them from the size of a small knitting-needle to that of a cedar pencil; but for still larger work we used to make them of boxwood, which answered very well. We had various other contrivances for special work, which, however, need not be detailed here, as some of our many "dodges" will probably be described on a future page, when speaking of our amateur engineering, and the better lathe which we afterwards obtained. This last, nevertheless, did not displace the one here described, which always kept its place in our workshop, and often proved even the more serviceable of the two for certain kinds of work.

CHAPTER III.

WORKSHOP APPLIANCES.

THIS chapter will be devoted to a description of other of our workshop appliances, of which many were home-made, and answered so well, that we never found it necessary to provide more expensive appliances from the tool shops. First there was our drilling apparatus. We had so often seen the village blacksmith at work, with his old-fashioned crank drill and press frame, that we thought we could hardly do better than adopt it in a modified form—*i.e.*, we did away with a certain heavy and clumsy contrivance overhead—a long beam hinged at one end and fitted with a weight at the other. We replaced this affair by a frame of wood, as we had not then funds for much iron-work, and after we had funds we used this drilling bench for years. It consisted, first of all, of a strong stool, which, with the rest, we have only shown in profile and section,

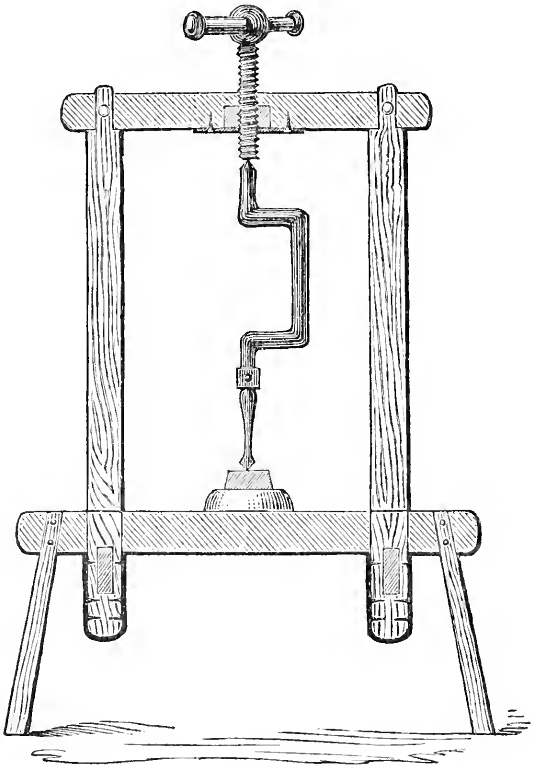

Fig. 5.—Our Drilling Machine.

to make the construction more clear. The bench and cross piece above were of ash, as we considered that upon these the strain would come; but the uprights were of deal, because the tendency would only be to stretch these lengthwise. They were mortised into the bench and cross piece, and pinned through the latter with oak pins or trenails, but under the bench they were fastened by wedges, which could be knocked out and the whole frame removed, leaving the stool free for sawing or any other purposes. The lower mortises were strapped with hoop iron, to prevent any chance of their being split out by the wedges. The stool was two feet long and ten inches wide. The uprights three inches wide by two thick, the widest sides in and out, and the top four inches by two, the broad surfaces above and below—so that, as seen in the drawing, the edges of these parts are shown. The feeding screw was picked up at an old iron store, and the blacksmith fitted to it a nut which we let in flush in the upper bar, putting a plate on below to keep it in place. As the strain was in the contrary direction, this did not need to be specially strong, and four three-quarter screws held it very well. We could thus oil the nut at any time by taking off the plate. The brace we of course bought, as well as the drills, but we afterwards learned to make the latter ourselves, to our great advantage. To hold the work to be drilled, we used all sorts of different contrivances—blocks of wood sometimes on each side of it, wedged up; iron bolts and clamps through the bench, with nuts underneath, and various extempore arrangements. We also made mortises in our vice bench, and could mount the same frame over this when we pleased, so that work which we found it impossible to secure upon the drilling-bench, could be held in the tail vice itself. Altogether, we never had a more serviceable tool in our workshop than this rough-and-ready affair, which was often put to somewhat unfair tests when we had to drill larger holes than usual.

To set the drills upright for work, we used a plumb-line in two directions, standing a little way off, and holding the line between the eye and the drill, and shifting the work until the drill was truly vertical in both directions. All we then had to do was to work away at the crank, and feed with the screw, and the drill would descend perfectly true, and bore very rapidly. I think we gave ten shillings for the brace with six drills, the screw and its nut, and the raw material of which the bench and side pieces were made. The screw I believe was an iron bench screw, of which probably the nut had been lost, and thus it had found its way first to the scrap heap, and then to the rag, bone, and old iron merchant, who had disposed of his donkey-load to the keeper of a marine store. It would be curious to trace the history of such a screw through the various phases of its existence, until at last it returns to the melting-pot from which it originally came.

I think if a thing of this sort could write its experiences, and describe the scenes it had witnessed, the homes it had visited, and the characters it had met, the result would be such a book for boys as I shall never write as long as I live. Our old screw, however, was silent (unless it wanted oil, and then it sang loudly, or wailed sadly), and if "it could a tale unfold," it never did so.

For a long time we were very badly set up in screwing apparatus. This was an expensive item, and the most we could do was to possess ourselves of a screw-plate with double handle, and three or four holes, and a smaller one of clock-size with eight. The taps were few and bad, but we found means to increase these from the plates themselves, and though not of first-class pattern—not being grooved, but merely squared up—they did pretty good work, good enough for most of our early engineering requirements. One or two holes of the plate were indeed useless, from having been used upon very hard steel, which had worn down the threads, but we could cut screws from about three-eighths down to one-sixteenth very well.

Our great ambition was, however, to become possessors of a stock and dies, and we searched catalogues, and advertisements, and sale bills over and over again, but could meet with nothing suited to our finances; and not till we had made a good many steps in advance of our early trials at engineering did we succeed in obtaining this most desirable screwing apparatus. It came, nevertheless, in due time, like many other tools and workshop appliances, and, perhaps, on the whole, it was well that we did not possess a stock earlier in our career, for our inexperience would in all probability have caused its destruction.

With the few appliances alluded to, in addition to files and such-like, we worked steadily at all kinds of mechanical jobs for two or three years, and by this time we had grown from little boys into big ones, and both brain and hand began to yearn after somewhat better tools, and work of a higher quality. We began to find our lathe especially unfit for real engineering operations in metal, although sufficient for occasional work ; and we determined, after due consideration, to replace it by one with a fly-wheel and treadle, mandrel and chucks.

How we talked over this work! and how many plans we drew before we decided upon the best ways and means. The bed was to be wood, of necessity; but we determined upon having beech very carefully planed with an iron plate on the upper surface, put on with countersunk screws, and filed up as true as we could succeed in making it. It was to be six feet long, because, although we noticed that a great number of lathes were made with four-feet beds, we considered that it would be as easy to make one two feet longer, and that it would be much better for wood-turning, in which the work is often of some length. The standards to support this bed we also determined should be made of beech, and the fly-wheel quite plain, not grooved for gut, but suitable for a strap, because we found this could be easily met with at an iron store, foundry, or machine shop, secondhand, whereas a bevelled and grooved one could only be had at a lathe-maker's.

We knew, however, that this would not give us the slow speed necessary for metal turning, but we thought we could easily turn a small pulley or drum of wood with a hole for the axle, and that we could attach it also by a couple of screws to the spokes of the fly-wheel, to secure it from slipping round upon the axle. This we subsequently made, and very well it answered. The main difficulty, we felt, would be the mandrel and its fittings, and the back poppit; in short, the upper works of the lathe.

In the midst of our deliberations, and when wooden poppits and very inefficient substitutes for mandrel and collar were determined on, a kind friend who heard of our dilemma, and was charitable enough to appreciate our various attempts to make our own apparatus, brought us an old rusty mandrel fourteen inches long, with a worm-eaten pulley and some half dozen short lengths of screw threads cut upon it. Eagerly we accepted such a prize. It was apparently from some rejected and disused brass-turner's shop, for there was a bit of brass rod broken short off inside the female screw intended for the chucks. The first operation was to clean it, which we commenced by boiling water and soda, with a very hard scrubbing brush and sand. This soon got rid of a thick mass of old hardened oil and dirt, and enabled us to see something of the bright but tarnished metal below. Testing the latter with a file, we found that it had been hardened at each end, and was a promising concern. In fact, the only really bad part about it was, that one set of guide threads for screw cutting was damaged, but not so as to have become absolutely useless. There was one point, however, which we regarded as a drawback, and this was the length of the mandrel, which would have the effect of shortening the bed; we therefore added a foot to the latter in our plans, determining to make it seven feet instead of six. The pulley was wholly gone, but it was now a very easy matter to replace it, as we were quite used to the pole-lathe. We began by roughly sawing out a round piece of beech. We then drove it tightly upon the mandrel, mounted this in the lathe, and turned up the wood. It therefore proved (as we foresaw) absolutely true, and being intended for a strap, we merely turned it slightly large in the middle, rounding it off each way. I forget who put us up to this now well-known secret of turning pulleys to receive straps; for I remember that it was at that time customary to turn them with a rim on each side to keep the strap from slipping off, the result being that the said strap generally found its way up on the rim, and insisted on riding partly there instead of on the flat surface. It was, however, discovered by some observant mechanic, that if a strap were made to run upon a conical surface, its tendency was to run up towards the largest part, instead of slipping down in the other direction, as would be expected. If, therefore, two short cones were placed base to base, *i.e.*, with their large ends together, the strap would evidently keep on and retain its place in the middle of such pulley. This is the form now universally adopted, except that the sharp edge at the meeting of the cones is always rounded off considerably, the pulley being simply larger in the middle than at the other parts. This will be evident from the sketch given of our renovated lathe in fig. 6. The screw guides cut on the mandrel are seen at CCC; being of a different pitch, one had eight threads to an inch, the next twelve, and the third sixteen. There had been one of twenty, but it was so damaged as to be useless, and these three pitches sufficed for our need. At A is seen a block of mahogany screwed to the bottom of the poppit, and having three vertical mortises and three horizontal ones opening into the others. In the vertical ones were three squared plugs of wood, and in the horizontal ones were wedges which, being driven in, raised the plugs until their upper surfaces touched, and pressed against the guide screws sufficiently to be deeply indented by them. Thus, if the mandrel was free to revolve, and also to move along horizontally in its bearings, and one of these plugs was made to press

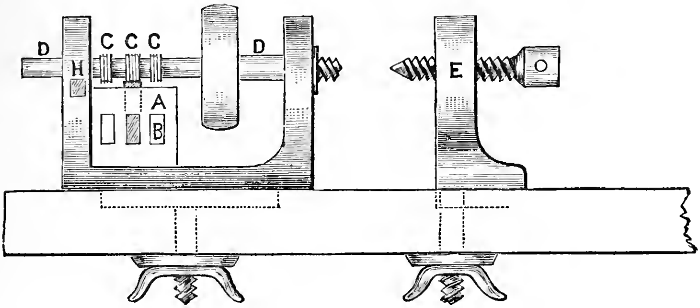

Fig. 6.—Our Renovated Lathe.

against its screw, the mandrel would of necessity traverse end-wise at the same rate as the pitch of that particular guide screw. Hence, this is called a traversing mandrel, and a screw to match any one of the guides is easily cut upon wood or metal by merely holding a point tool or a chasing tool of the right pitch quite still upon the rest. The traverse is from left to right, the mandrel advancing in that direction in its collar, so as to make the screw a right-handed one. The mandrel is quite cylindrical at DD, where it passes through its collars.

Another wedge may be noticed at H, in the left-hand standard of the mandrel head. This was fitted to raise a slip of steel, so as to make it enter a shallow groove turned in the mandrel at that point, which then prevented its traverse. This was used when the lathe was not required for screw-cutting; a shoulder in front, just behind the screw on the nose of the mandrel, prevented it from running back in its bearings, and took the pressure of the screw in the other or back poppit. This latter was merely cut out of a bit of sound beech, and carefully bored to receive a pointed screw. It was not very handsome, perhaps, but answered its intended purpose, and we improved the general appearance of the poppits by rendering them as smooth as possible, and giving them a couple of coats of good black paint. We took a great deal of trouble to rig up our French mandrel, and spent on it a vast amount of patience, which was on the whole well rewarded. The stand, with crank treadle and fly-wheel, are omitted in the drawing, as the main object of the latter is to show the general arrangement of the traversing gear and its fittings. These French mandrels are not often met with now, but very similar ones may be found in the shops of some soft-wood turner's, as they are far cheaper to fit up, and quite as effective in use as the more neat and costly ones generally found in modern amateur's lathes. The long mandrel is, moreover, an element of steadiness, and is not without some peculiar advantages.

I must now give an account of some of our lathe fittings, without which we could not have made any practical use of it. We intended, if possible, to turn articles of brass as well as of wood; but for the small and light articles likely to be undertaken by us, we rightly imagined that wooden chucks would suffice, if made with iron ferrules to prevent splitting. One chuck, however, we found it possible to obtain in metal, viz., a taper screw fitted into the centre of a brass plate, which only needed to be attached to a wooden base by four ordinary wood screws. We procured two of these, one with a large and the other with a small centre screw. In order to mount these properly, it was necessary to cut an internal screw in the blocks to which they were to be attached, of the same thread as the mandrel, viz., eight to the inch, the same pitch as the coarsest of the guide screws. To accomplish this, it was, of course, necessary to mount the block on the mandrel with the hole to be screwed outward. We therefore sawed off a piece of dry beech about an inch longer than would be required for the chuck, and bored it with a centre-bit at one end, so that the mandrel screw would almost enter it. We then forcibly screwed it on, allowing the mandrel screw to cut its own thread. This it did sufficiently well to secure the work, and enable us to turn it, and accurately square up the end. This end we now bored as it ran in the lathe, making the hole the exact size of the smallest part of the mandrel screw (*i.e.*, its size between the threads, which we had previously ascertained by measuring it with callipers). We now had to cut the inside screw, our first attempt with the new mandrel.

We had been advised to procure a small set of chasing tools, which, in point of fact we had learnt to use fairly well, even with the pole-lathe, and we had a pair of the pitch required. But we had as yet no experience of a traversing mandrel. Holding the tool across the rest, which we turned round so as to stand across the end of the work, we freed the mandrel to allow it to traverse, and drove in the wedge, so that the small block above it geared with the screw above it. We then found that by giving the crank a half turn to and fro, the mandrel advanced steadily as required, and traversed backwards and forwards evenly. But at first we found that the rest was placed too near, so that the work touched it every time it advanced. This was easy to remedy, but we also found that the moment the points of the inside screw tool touched the work, the tool itself was carried forward instead of cutting a thread. We had, however, as yet no slide-rest to hold the tool, and had to contrive a temporary apparatus to suit our present purpose. We saw that it would be necessary to have some means of shifting the tool somewhat towards the left hand as the cuts deepened, but otherwise it must be motionless; to do this effectually would need some kind of slide, but, considering that the depth of the screw-thread was at most but one-eighth of an inch, and that this was consequently the full amount of traverse necessary for the tool, a slide seemed hardly requisite, especially as screw-cutting would not, in all probability, be a very frequent occurrence. Moreover, we soon found it unnecessary even to provide for a traverse of the tool of *this* amount, because as soon as a thread was fairly traced, we discovered that it was better to stop the traverse of the mandrel and finish it by hand, the thread already cut sufficing to draw the tool forward at the proper rate. After divers sketches and suggestions of a more or less complicated character, we cut out a block of ash with a stem to fit into the socket of the ordinary rest, and cut a groove lengthwise, forming a narrow channel in which to lay the tool, but which was wide enough to allow it a little movement sideways. In this we laid the chaser, and found that we could very easily steady it by grasping the rest and the tool together, and after a little practice we managed to cut our screws very easily.

This first attempt was a little less satisfactory than subsequent ones, but was sufficiently well done to serve the required purpose. We did not cut the threads to quite their full depth, and then by screwing the block forcibly on the mandrel, after rubbing a little soap upon it, we finished it to an excellent fit, as this process compressed the wood and made the screw threads smooth and polished. When cutting screws in this way in boxwood, we did not find it necessary, however, to resort to this mode of finishing them, as that wood being very hard and compact, will allow a screw to be chased at a slow speed, but woods like beech or ash, that require to be cut at great speed in order to produce a smooth surface with the tools, cannot be thus screwed in an equally satisfactory manner, but are left by the tool in a comparatively rough state. Screws can only be *well* cut in these by what are called V tools, which cannot be always procured except at the London tool shops. They are in form like a folded slip of paper, and are made exceeding sharp on both edges.

We had made out of a piece of dry and sound boxwood an exact copy of the nose of our mandrel, so that we could at any time test the accuracy of our chucks by screwing this into them without the necessity of removing them from the mandrel; and as I may be addressing young mechanics, let me tell them by all means to follow our example, as the convenience is very great.

Having finished the screw and found it correct, we cut off the wood with a parting tool to insure its being perfectly true, and then, screwing it on the mandrel as already described, still further finished it with a chisel. We also recessed the end, so as to allow the brass plate to fit in flush and to be held centrally without shifting, while being secured by three-quarter inch screws. As we had taken extreme care to level the bottom of the recess, we found that when all the screws were in place and the chuck finished, its pointed taper screw was perfectly true with the back centre.

Both the taper screws having been fitted in the same way, they were now used as chucks to hold other pieces requiring a similar process of boring and screwing to make cup-chucks. Some of these we made of boxwood, because the screws were more likely to remain for some time true, but as we soon found that the very hardness of this wood prevented it from gripping work as securely as other more elastic woods, we made other chucks of beech, ash, and hornbeam, the latter wood proving excellently suited for such work.

The wooden chucks, intended to be hollowed out to receive any object to be turned, were very simple affairs, merely blocks of wood bored out and screwed to fit the mandrel, turned on the outside, and fitted with an iron or brass ring, so that they could not be easily split by driving the work into them. Some of these rings were forged by the blacksmith—others were bits of stout tube. In short, whenever we came across a bit of metal likely to prove serviceable, we made a prize of it, and put it by for future service. For ferrules for our tool handles we got bits of gaspipe or old gun barrel, which we cut off with a hack-saw, and turned up bright after they were in place on their respective handles.

Our lathe was now in fair condition for use, and we only needed to add to the stock of apparatus from time to time as it might be needed. After the experience we had necessarily gained in fitting up this lathe and the previous one, we felt it very unlikely that we should meet with difficulties of an insurmountable character in the amateur engineering work which we proposed to carry on. We had, in fact, learnt to make light of difficulties, and had gained a habit of perseverance and ingenuity in devising makeshifts to meet casual emergencies which ever after served us in good stead. If we had not precisely the tool or the apparatus required, we contrived to make something else serve instead, and thus, while we saved money we avoided any useless accumulation of tools.

The list of turning tools in our possession, all neatly handled and ranged in a tool-rack by the lathe, was as follows :—

Two gouges.
Two chisels.

Three pairs of screw or chasing tools.
One point tool for brass.
One round-end ditto.
One heel tool for roughing down iron.
Two gravers.
One flat or planishing tool for brass.
Two side tools for brass.
Six variously-shaped tools for hard wood.
A pair of in-and-out callipers.
A pair of compasses.

The drills used in the carpenter's and smith's braces we used also in the lathe, having made a boxwood chuck with a square hole in the centre to receive them. The back poppet, however, of our lathe was not a very good form for advancing any work against the drills, but we made it answer fairly well by turning a thimble or flange to slip over the point, sufficiently loose not to revolve with the screw, but fitting it closely enough not to shake about when in use. This, being made flat and true, presented a broad surface against which the work could abut, and by which it could be gradually and steadily advanced.

We subsequently managed to pick up secondhand a far better poppet of iron with a cylinder and leading screw, such as is used in all the better-class lathes of the present day, but this was not obtained for three years after we had fitted up the one described.

I must now describe some of the work which we managed to produce with the above tools.

Chapter IV.

OUR WOODEN CLOCK.

ABOUT this time we had come into possession of some old books on mechanical subjects, in one of which was a description of a curious German clock, in which a wretched individual was decapitated every two or three minutes, his head being on each occasion deposited in a plate held by the executioner's assistant. No doubt it was meant to represent the decapitation of John the Baptist, as there was a painting above it of a sacred character, but very roughly executed, and (as was stated in the description) partly obliterated in the original. The beheading of the figure was done in a manner short, sharp, and decisive, at the end of the allotted time, but the head gradually went back at each tick of the clock until it rested on the neck of the condemned victim, where it remained until the time came for its next removal. The description of this old clock excited our ambition to reproduce it, and after much calculation and much sketching of the various details, which culminated in what we were pleased to call "a working drawing," we began our work with great zeal, and after a good deal of labour and some partial failures, we actually accomplished it, and even added other mechanism to the original design. Our chief difficulty arose from the fact that no description was given of the details of the machinery, nor did we know much about clocks at that time. We had consequently to read up our subject from the commencement, making notes as we proceeded of the principles involved. These notes I append here to show other boys our methodical way of learning our new trade of clockmaking.

PRINCIPLES OF CLOCKS.

1. The main consideration is the pendulum, which is, in fact, the actual timekeeper, the spring or weight and the wheels being necessary only for the purpose of recording the number of beats made by the pendulum, and for keeping it in motion.

2. The number of beats made by a pendulum in a given period depends entirely upon its length. If a

weight is hung on the end of a string, and is made to oscillate from side to side, these oscillations will occur at equal periods, whether the arc described by the swinging weight be large or small, for any given length of string.

But this is only precisely true up to a certain point for a pendulum or suspended weight, because the arc which it describes is a part of a circle of which the point of suspension is the centre, and the arc of which the above rule of oscillation is always true is not part of a circle but of a cycloid. The difference, however, between the arcs, for the short distance of the swing of a pendulum, is so small, that it may be considered that a pendulum of a given length does actually perform its oscillation in equal times.

To impress facts like the above on our minds, we always resorted to practical experiments, especially in any case where a mechanical law appeared incomprehensible. In this case, for instance, we fancied that the pendulum *must* of necessity take longer to traverse a large arc than a small one; but after hanging a weight to a rail by a piece of string, and timing its oscillations, we saw at once that, when first started on a large arc, the impetus carried it forward rapidly past the lowest point and up the opposite hill, and that this impetus became less and less as the arc of oscillation grew smaller, so that the weight took as long to traverse from side to side a couple of inches or less as it had taken at first to accomplish its longer journey.

While watching the swinging of our string pendulum, it so chanced that one of us began to whistle a tune, and we noticed how beautifully our apparatus answered as a timekeeper. We had but to shorten it to make it beat quick time, or lengthen it for a slow march. We thus unconsciously invented the tape and weight now often used to teach music in schools; the tape being marked at varying intervals, at which it is to be held in the finger and thumb, and the oscillation of the weight marking time accordingly. We did not, however, attach any great value to our discovery, because, being but boys, we concluded that others besides ourselves, and of maturer years, must necessarily be well acquainted with a fact so apparently simple, and so easy of practical application. In this way, no doubt, many inventions are lost from time to time, and we have since learned never to take the knowledge of mankind for granted, but to make notes of every fact we may chance to discover for ourselves, and to add suggestions of any possible application of it which may from time to time occur to our minds.

We found, in short, that this habit of observing and noting simple facts had resulted in some of the most important discoveries and inventions ever made, including the steam-engine and electric telegraph, and that not only had our greatest engineers been invariably accurate observers of natural facts, but also unwearied experimenters, who carefully wrote down the results of their experiments, to assist them in subsequent investigations. Our own further notes about pendulums were as follows :—

Thirdly, The string being impracticable in a clock, and the pendulum requiring a rigid bar to support the "bob" or weight, this bar needs to be theoretically of invariable length, and freely suspended, so that its oscillations shall not be retarded by friction, nor caused to vary in duration by the effects of temperature. These requirements become in practice sources of much difficulty, owing to the fact that metals expand by heat and contract by the action of cold, and therefore a bob suspended from a wire, as in common clocks, would not give the same results as a timekeeper in winter and summer, not even under the variations of temperature occurring almost every day. Wooden pendulum rods are less liable to vary in length, especially if varnished, and this is a very good material to use, where more complicated means cannot be employed, to compensate the expansion and contraction of metal rods.

Fourthly, A long rod keeps time better than a short one, because its swing is steadier, and it is less easily checked or stopped by slight causes, and, on the whole, a pendulum beating seconds is the best to use where a long clock-case or plenty of room is available, and appearance is not of importance. A seconds pendulum is 39·37 inches long from the point of suspension to the centre of gravity of the bob for northern latitudes, which is quite near enough for boy clockmakers, at all events; but it is as well to note that this pendulum, if used near the equator, would cause a clock to lose time, because the force of gravity which acts on falling bodies, and, in fact, *causes* them to fall, and causes the pendulum bob therefore to descend when lifted, is less at the equator than elsewhere.

Ffithly, As our first clock was meant in a great measure to give us an insight into the mechanism of clocks, and would in all probability be far from perfect as a timekeeper, we considered that wooden wheels might be very well employed throughout, except in the scape-wheel, which would be constantly acted upon and rapidly worn by the pallets of the pendulum. This we saw at once must be made of metal—brass, if we could get it—tin, if we could not. The pinions we intended to make of wire if possible; if not, we proposed to cut them as well as we could out of the substance of the axles, which were to be of wood, with wire pivots driven into each end.

We next proceeded to calculate our wheel train, as it is called,—*i.e.*, to find out how many teeth each wheel would require, and how many we must have on the several pinions to give the required speed to each. The scape wheel, acted on by a seconds pendulum, we found must have thirty teeth, as it must revolve once in a minute to receive a minute hand on the end of its arbor, the several teeth escaping on each double swing of the pendulum which beat seconds. We had nearly fallen into the mistake of making our scape wheel with sixty teeth; but a study of an old Cyclopædia showed us that, although a tooth escaped at each beat at one side of the wheel, the tooth diametrically opposite to it was instantly caught on the sloping face of the opposite pallet, which was so formed as to give the pallet a slight impetus each time it oscillates, so as to maintain the motion of the pendulum. Thus, practically, only half a tooth escapes at each single beat of the pendulum, and thirty teeth are required instead of sixty. This wheel, revolving once in each minute, we had to arrange an intermediate one, gearing into that which would carry the minute hand, and which must, therefore, revolve once in each hour, or sixty times as fast as the escape wheel. This escape wheel, with a pinion of eight leaves, therefore, we found must turn a wheel of sixty teeth, which, with its pinion of eight leaves, must gear into one of sixty-four teeth to carry the minute hand. Then comes the barrel, with its string and weight. The spur wheel not being fixed to the axle, nor connected rigidly to the barrel or drum, as will be explained, the pinion of eight leaves of the minute-hand wheel turns on a wheel of ninety-six teeth in connection with this drum,

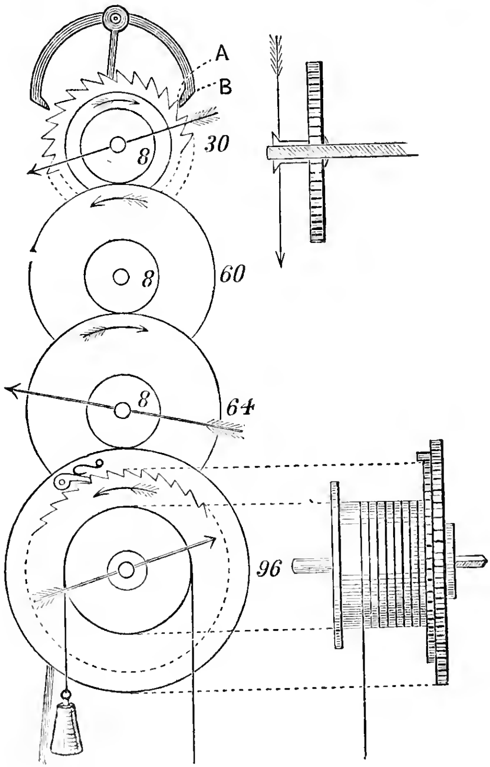

Fig. 7.—Clock Train.

which turns but once in twelve hours. To enable our young readers more fully to understand the nature of this train of clockwork, a sketch is appended here, the teeth being omitted. Teeth, moreover, would be unnecessary if the sizes of the several wheels and pinions were correct, and there was no slipping likely to take place, and this *rolling* contact, as it is called, is still used in various machines, but not in clocks. The number is affixed to the wheels to specify the number of teeth in each, while the number 8 is that of the pinions. These, it must be understood, are small wheels fixed on the axle of the large ones, either close to the latter or at the further end. Beginning at 96, the main, or great wheel, as it is called, which turns once in each hour, we see it driving the pinion of eight leaves of what is called the *centre* wheel, because it is commonly so placed that its axle, carrying the minute hand of the clock, shall project through the centre of the clock-face. Ninety-six being twelve times eight, it is plain that while the great wheel revolves once, the pinion will revolve twelve times; and as the great wheel revolves once in twelve hours, this will revolve twelve times in the same time, or once in each hour, which is just what we require for the long hand of a clock. Of the *short* or hour hand, we shall speak presently, as it is not driven in any part of this train, but by wheels just below the dial-plate.

As the pinion revolves once in an hour, the spur wheel 64 will do the same, because it is on the same axle; and as there are eight times eight in sixty-four, the pinion and wheel marked 60 will revolve eight times while the centre wheel revolves once—*i.e.*, eight times in an hour. Now this works into a pinion of eight leaves on the arbor of the minute or scape wheel, and eight will not "go" into sixty, as boys say, without leaving a remainder. However, it will "go" seven times and four over, which is $7\frac{4}{8}$ or $7\frac{1}{2}$ times; that is to say, this wheel will revolve $7\frac{1}{2}$ times while the second wheel, 60, revolves once. Therefore, while the latter revolves eight times (*i.e.*, each hour), the scape wheel will revolve $7\frac{1}{2}$ times multiplied by eight, which equals sixty; and this is again just what is required to carry the seconds hand. We have worked upwards from the great wheel to make the relative speeds of the wheels clear to the reader, assuming that this great wheel revolves once in an hour; but although the number of the teeth are arranged for this speed, the governing power is the seconds pendulum working on the teeth of the scape wheel. It would, however, come to the same thing to begin with this wheel as revolving once a minute, and so to work from it down to the great wheel which drives the whole.

The next consideration was the pendulum, or rather the pallets, which were to act upon the scape wheel.

We were sorely puzzled for a time between anchor pallets, dead beat, recoil, pin escapement, and others, of which we found accounts in some old books; but for our first clock we came to the conclusion that the old-fashioned anchor would be easiest to make, because it only needed sawlike teeth on the scape wheel, whereas the dead-beat pallets required teeth of peculiar construction, which we doubted our ability to make.

Eventually, we picked up a wheel and its pallets ready made at a clockmaker's, who kindly presented us with this important treasure, and took some pains to point out to us the principles upon which it was constructed. The pendulum, as already explained, is, as he told us, the timekeeper, but it would soon cease to swing if left to itself, and the train of wheels set in motion by the weight is necessary to give it through the scape wheel a slight impulse to and fro, to keep it in motion. One side of the teeth of the scape wheel are radial, the other sloping, and in this form of wheel the latter are the foremost, and fall in succession on the ends of the pallets. These, it will be seen from the accompanying figure, are so shaped that the teeth falling on their rounded faces are first checked, and then tend to push the pallets from them, and so give swing to the crutch or wire to which they are fixed, first in one direction, and then in the other, one of the curved faces of the pallets being on the outside, and the opposite one on the inside.

In the drawing of the clock train, the tooth, A, has just dropped upon the inner rounded face of the pallet, B, which cannot get free until the pendulum has swung far enough to allow it to escape. The tooth on the opposite side, however, has already escaped from the left pallet, upon which its successor will fall as soon as A gets free and advances, the scape wheel moving in the direction of the arrow.

In the days of our boyhood there were many clocks in use fitted only with an hour hand, and as there appeared to us certain difficulties connected with the minute hand, which would need what is called dial-work, if the two hands were central, we decided to make use of a plan, which we afterwards learned was not unusual in astronomical clocks, but which we felt at the time to be a serious departure from ordinary rules—*i.e.*, we fixed the hour hand to the axle of the great wheel of the winding barrel, which necessitated its going round backwards, the minute hand retaining its place on the pinion of the centre wheel. The appearance of the clock-face was consequently that of the accompanying illustration, in which is also displayed the scene of that dreadful, but constantly recurring, execution of the criminal already referred to. We discarded, however,

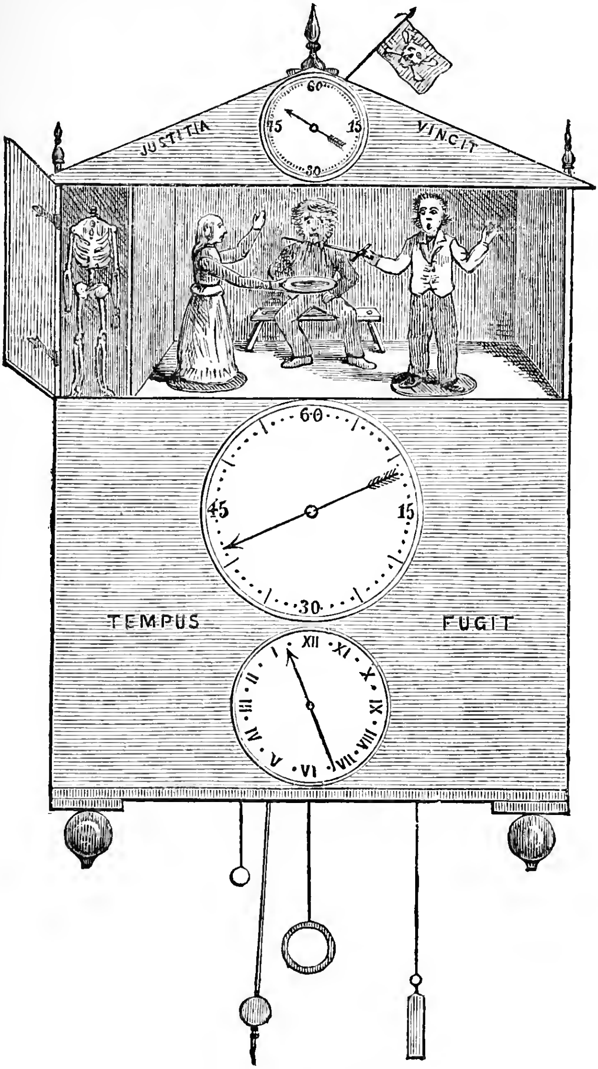

Fig. 8.—"That Awful Clock."

the original characters, as scarcely in accordance with our ideas, and called the tragedy the execution of the tyrant Bluebeard. I am afraid our carving of the wife-destroyer in question would scarcely have found a place at the Royal Academy, the figure rather resembling one of those Indian or Chinese idols, or "Samis," to be seen at the British Museum and elsewhere. We endeavoured, however, to produce a physiognomy of the ferocious type, which a blue beard of wool considerably enhanced.

This subject enabled us, however, to add one or two startling accessories, which were very effective. We made at one side of the stage a cupboard containing a headless skeleton, popularly supposed to be that of one of the luckless wives. Anatomists might possibly have been found to suggest that a mouse had originally owned the bones, but anyhow it was a skeleton, and a real one, and the door of the cupboard which contained it was forcibly flung open each time that the executioner did his duty, while at the same moment, two or three strokes upon a deep-toned bell proclaimed the sentence of the law to have been duly carried out. A black flag was also hoisted, and remained a few moments as a silent corroboration of the fact.

There is so much amusement always attaching to automata of the above kind, that all the details of the ways and means will be added. Most of such movements are very simple, and they become all the more amusing by being accomplished in that peculiar jerky style with which, to this day, the figure of the cuckoo performs his part in the Swiss clocks, which are as much prized as ever, although so comparatively common.

Let it be noted that a woman holds the dish for the reception of the criminal's head. The female in question, so young and so lovely, is supposed to be that happy but inquisitive survivor who held the position of last wife to the tyrant; and we subsequently regretted that we had not placed " Sister Ann " upon the house-top waving her hand to the expected brothers. The difficulty resulted not from our lack of the requisite mechanical skill, but from the fact that the decapitation of Bluebeard showed the brothers in question to have already arrived upon the scene.

We must now recur to the clock train, of which a side view is given here in fig. 9, in its place in the framework, which was made of beech, the holes being bushed with little bits of brass wire, drilled to receive the pivots of the several spindles. The numbers of teeth on the wheels and pinions are here specified as before, but the way in which the latter gear into each other will be more clearly understood, as the axles or arbors of the wheels are clearly displayed. P shows the position of one of the

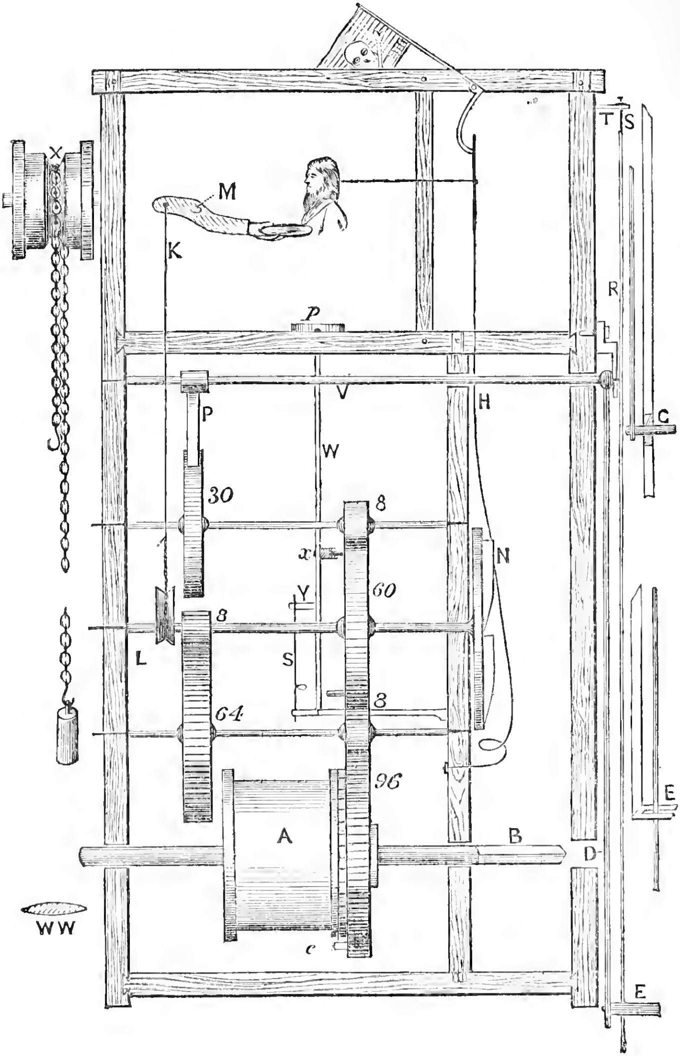

Fig. 9.—Clock Train.

arms of the anchor pallet, attached to the metal rod V, called the verge. This passes through the inner frame at H without touching it, and also through the back frame, and is pivoted on a piece of brass of the form shown, which is screwed to the woodwork. This was done partly to insure the easy working of the pendulum, and partly for the greater ease of getting the verge into its place. D is called the crutch, and is formed of a stout wire screwed into a small boss upon the verge. It is bent out at E, or has another wire inserted at that point, which falls into a slot in the rod R of the pendulum, as shown again at G, or a fork is made at E, in which the pendulum hangs. The pendulum, therefore, it will be seen, is suspended independently of the verge and pallets, being hung from a projecting stud at T by means of a thin spring, S, or a bit of silk or other substance allowing it to swing easily and freely. In our clock, the pendulum of wood had a saw-cut made at the top extending half an inch downwards, and into this we inserted a bit of watch-spring ground very thin. This was slipped into a saw-cut in the stud T, and secured by a pin passing through it. The form of the rod was like W in the cross section, that it might oscillate with little resistance from the air—a refinement scarcely necessary, considering the general nature of the workmanship and design.

It was necessary to wind the clock from the back, owing to our putting the hour hand upon the spindle of the drum and great wheel. The squared part of the spindle B was therefore made long enough to reach the back frame, in which an opening was left for the key. This we subsequently found so great a drawback, necessitating our taking down the clock to wind it, that we grooved the barrel like X, and made use of a chain which merely hung across it in the groove, and had sufficient hold in the latter to prevent slipping. To wind it, we then only had to lay hold of the other end of the chain, which had a light weight attached, and pull it, the ratchet and click answering the same purpose as when we used the drum with a long cord wound about it. To insure the chain against any chance of slipping, we drove in all round the bottom of the groove short wire pins, which caught the several links as the wheel revolved.

The figures were made to perform their several parts in the following manner:—In fig. 8, it will be noticed that the executioner and vengeful wife both stand within a small circle, which represents a little platform pivoted vertically upon a wire axis. The arm of the woman, it will be observed, is also pivoted at the shoulder, so as to allow it to move up and down. The object of this is to cause her to raise the plate level with the victim's chin just before the fatal deed is done, immediately after which the head is carried forward upon the plate by the rotation of the fair lady upon her axis. The latter movement alone upon the part of the executioner enabled him to do *his* duty, which we compelled him to do at each quarter of an hour. All the movements were done by jerks, as usual in such automata, and which made the whole scene ten times more grotesque than if accomplished in a graceful manner. To begin with the executioner. The movement of this terrible person needed to be especially sharp and sudden; we therefore accomplished it by the release of a spring, bent gradually by a cam until the latter was released at the appointed time, and then gradually bent again until the fatal hour recurred.

In fig. 9, W is a stout wire pivoted at the lower end into a horizontal arm of brass attached to the frame; at its upper end it carries P, the circular disc on which the executioner stands. X is a flattened pin fixed to the upright wire, which is acted on by four projecting studs fixed at equal distances into the face of the wheel 60, so that one of these studs comes into action at each quarter of an hour. A second projecting pin, Y, is constantly pressed by the wire spring S, fixed below into the brass plate which carries the wire W. Suppose that in its present position the spring rests lightly against Y, and that the executioner's sword has passed under his victim's neck, the beard preventing the space between the neck and shoulders left to admit the sword from being seen. The figure must now gradually rotate on its axis, so as to draw the sword back again, and when a certain position has been reached the figure has to be released suddenly, and carried round by a rapid movement so as to cause the sword to pass through the neck, at which moment also the head must be jerked forward into the dish. This is done by the pins in 60 pressing against the little pallet *x* as the wheel revolves, by which action the other pallet presses back more and more the spring S. This will go on, causing the figure to rotate and draw back his sword until the pin escapes from *x*, when the spring S, being now fully strained, will be able to act suddenly on the pin Y, and the executioner will deftly repeat his fatal work.

We must now turn our attention to the head. This is fixed to the end of a steel wire passing *easily* through a hole in the inner frame. All the parts must be made to move as easily as possible, to prevent the clock from being stopped by their action. For this reason the spring S must be only just strong enough to give rapid motion to the figure. H is a long light spring of hammered brass or steel, fixed at one end to the frame, and at the other to the horizontal wire carrying the head. The latter, if blackened, will not show, the back of the stage being also painted a dark colour. N is a wooden wheel on the axis of the hour wheel, into which is fixed four stout wires bent as shown, which alternately act upon the spring H. They are bent so as to slope gradually from the wheel a short distance, after which they are parallel to the surface of the wheel; they then turn sharply down and are fixed into the wood. This sharp bend of each comes exactly opposite the pins on the other side of the hour wheel, and act at the same moment. The wire spring H is so bent and so placed that, as the wheel N revolves, the bent wires catch it first on their inclined part, which pressing back the spring, gradually draw the head of the figure back until it rests upon the neck, and remains during the time that the flat part of these wires touch it. But just as the sword of the executioner falls, the spring drops off the wires suddenly, and the head is shot forward in an instant upon the plate, looking as if wholly detached, especially if seen from below as the clock hangs on the wall. As the wheel continues to revolve, the spring is gradually pressed back again, rising upon the inclined surface of the next wire. What are at first sight complicated motions are thus readily produced by a few bits of bent wire. The arm of the woman is raised by an equally simply contrivance. An eccentric pulley of box-wood, L, is fixed on the axle of the hour wheel 60, the eccentric hoop or strap being a bit of wire fitting it easily, and twisted together at the ends. To this is attached a bit of silk, K, the other end of which is tied to an extension of the arm of the figure concealed by the dress, as is also the silk cord. The arm and its attachments only are here drawn. M is the pivot on which the arm is hinged at the shoulder. The eccentric is so placed that it will draw the string tight, and cause the plate to rise level with the head, just at the moment the latter is about to be cut off and thrust forward, so that it is apparently caught very cleverly. As the eccentric continues its revolution the arm with the plate is allowed gradually to drop, the plate being slightly weighted with lead to keep up a proper tension of the silken cord.

The black flag is hoisted at the moment of execution by the upper part of the long spring coming in contact with the end of the bent lever, and pressing it suddenly forward, thus raising its straight end, which forms the flagstaff. All the various movements have to be exactly timed, but present no great difficulty. The eccentric, for instance, is lightly pinned until its action has been tested, and then it is secured. The wheel is also tested before being fixed on its axle, and the springs and wires will need only a little careful adjustment by means of the pliers. The long spring may be of watch-spring, straightened by being pinched in a fold of stout leather, and drawn a few times between the finger and thumb or the jaws of a vice until the curl is taken out. Brass wire, however, is equally good for the purpose, and if hammered or drawn through a conical hole in a steel plate, so as to compress and harden it, is largely used for this purpose by organ and harmonium makers and others; and if a turn or two is taken by winding it round a small iron rod, as shown here, makes a pleasanter, and to some extent a better, spring than the steel. If used, it should be flattened where it has to act against the lever of the flag, or any similar part of the mechanism. The opening of the skeleton cupboard is not detailed on purpose to exercise our reader's ingenuity. It was made to fly open with a jerk a few seconds before the decapitation of the criminal. The ingenious youngster who may chance to read these pages should devise various accessory movements—as, for instance, a bell to strike before the execution takes place. A small lathe and a very few simple tools and materials only are required to make the above. The clock will possibly not keep very good time, owing to the extra work laid upon it of moving the automata, but if care is taken not to overload it, it will answer fairly well as a timekeeper.

Chapter V.

SOME MORE AUTOMATA.

WE succeeded so well with what subsequently obtained the name of "that awful clock," that we thought we would try our hands at a few more of these mechanical toys, and among them, our next attempt was a piping bullfinch, such as we had read about, but not at that time seen. At first we did not hit upon the best mode of producing the bird's song, but it answered fairly enough until we found out the better and simpler plan.

This very pretty little mechanical songster was first brought into notice at the Exhibition of 1851, where it found crowds of enthusiastic admirers. At Paris it met with equal honour, and, indeed, although called a piping bullfinch, the real toy was a number of birds on a tree under glass, hopping to and fro, and chirping and twittering most naturally, their wings fluttering and beaks moving, and even their throats expanding and quivering as if alive. They were formed as we made our own, of the skins of real birds over a framework of wire and wood, the skeleton being preserved where possible. Our own was, of course, but a humble affair, as we contented ourselves with a little movement of the wings and quivering of the beak, our chief attention being directed to the mechanical arrangements for producing the bird's song. This part of the apparatus we made so as to serve permanently, as we intended from time to time to change the warbler, arranging the notes to suit the particular bird. The lower part of the stand contained the mechanism, a tree branch forming the perch, upon which any bird could be mounted at pleasure in a few seconds. We had a linnet, goldfinch, and bullfinch, and subsequently added on a separate branch a thrush; and I still think that, for mere youngsters, we managed to give very good imitations of their respective songs. We subsequently, however, attempted a still higher flight, not by the addition of a skylark, but by an attempt to imitate the song of a nightingale, which, it is well known, has a greater natural variety of notes than any other of our native songsters.

We had first to consider the wind-chest or bellows, and here we found a few experiments necessary. Our first idea was to make a miniature pair of double bellows, like those of a blacksmith, to keep up a continuous blast, and to attach to the upper part a short whistle pipe, with keys like those of a flute, to be acted on by a series of little tappets on a barrel, pinned like that of a musical box. A trial of this, however, did not satisfy us, as it was found impossible to imitate successfully the trill or quiver of a bird's song. We consequently discarded the double bellows for a pair of single acting ones kept open by a spring inside; and on trying these with a common whistle of one note only, tapping the movable board of the bellows with the fingers, we found it more hopeful. We found, however, that although a whistle of one note would give, for that note, the kind of sound required, it did not answer so well with two or three notes and keys, but that it was necessary (as in a cuckoo clock) to have one distinct pipe for each note with its own separate single bellows, unless we inserted a wind-chest like that of an organ between the bellows and the pipes. We were decided on the latter course accidentally, by hearing an organist shaking upon two keys of very high pitch in an organ that was undergoing repair or being tuned, and the notes, chancing to be very nearly those required, sounded so birdlike, that we no longer hesitated to adopt the above plan.

We commenced by making a shallow box of quarter-inch deal for the top and bottom, but with the end pieces as well as the back and front of half-inch stuff, which at once gave strength and neatness to the work. In the top board were four holes for pipes, and under these were four pull-down pallets, like those of an organ, hinged with leather, the same strip serving also to face and render them air-tight. These were pulled down by brass wires hooked into eyes or rings in each, and they were kept up by springs also made of brass wire. The pull-down wires, hanging straight down from the pallets, passed of necessity through holes in the lower board of this case or wind-chest, through which it was necessary that they should move easily, but without allowing wind to escape round them. They were not indeed air-tight, but by careful drilling were sufficiently so for our purpose. Although, however, a little leakage was not likely to be of great importance, we glued a strip of leather along the bottom of the wind-chest, to form a kind of padding where the wires passed through, which, fitting closely round them, made the case tolerably wind-proof even under full pressure. As we foresaw difficulty in attaching the pull-downs to the pallets, we left the front of the chest open until they were arranged and hooked to their respective loops, and we also took care that the ends of the pallets should come as close to the front as possible, so that with a small pair of pliers we could easily manage the work.

In all our subsequent automata, as well as in this, we found that we always saved much time and temper by careful consideration beforehand of all such minor details. If every individual part is not planned with due care, it is almost sure to be found when too late that some wheel, or wire, or lever, cannot by any possibility be got into its place.

A story is told of an architect who, after he had planned a house, and had it partially built, suddenly discovered that he had forgotten to provide for a staircase, and as by no possible contriving could he afterwards insert it, he hit upon the Swiss method, and put it outside, introducing thereby a novel feature in English domestic architecture, and making a name and a fortune out of a mistake. It is not, however, easy to act in a similar way with a badly-planned piece of machinery, and an oversight in such a design entails a very good chance of failure in its working.

Happily a little forethought, and, let it be confessed, a little previously dearly-bought experience, enabled us to escape this dilemma, and we had no difficulty of the kind to contend with on the present occasion.

Having completed the little wind-chest, which was three inches long, an inch and a half wide, and an inch deep, we attached it to a framework which allowed the bellows to be placed below, leaving room above them for the working of the levers which were to act on the pull-downs. A sketch will, however, make this

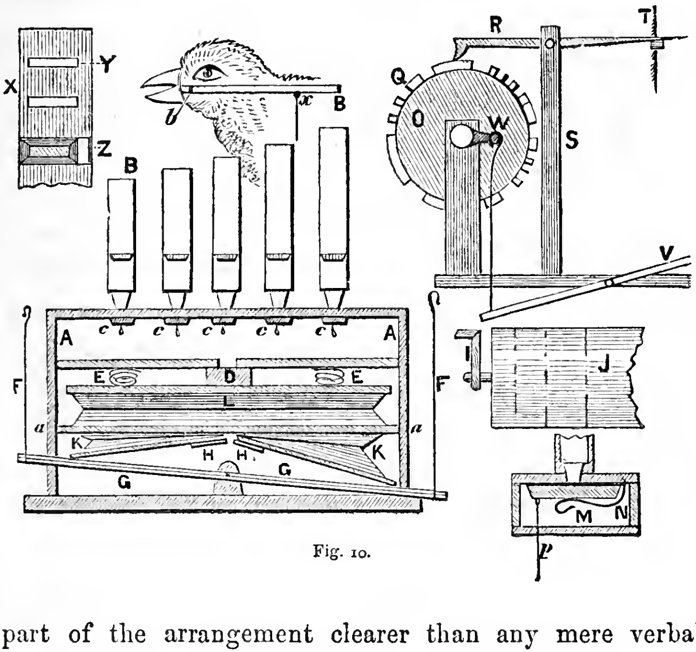

Fig. 10.

part of the arrangement clearer than any mere verbal description.

A section of the wind-chest is given at AA of fig. 10, and this was concealed in the stand of the automaton. The pipes, BB, which are here represented as standing upright, were also laid flat on the top of the wind-chest, a short bit of lead gaspipe connecting them with the wind channels and valves below. These valves or pallets are seen in cross section at CC, and again at Z as seen from below, and at MN as seen from one side. In the latter figure, M is a *cross* section of the wind-chest with the lower end of a pipe inserted, P is the pull-down wire, and N the spring which keeps the pallet shut. A light spring sufficed, as the tendency of the pressure of wind in the chest was also to keep the valves close.

KK are feeders, or the movable parts of the bellows hinged at HH. These drive the wind into the upper part or reservoir, L, through two valves in *aa*, the fixed board which separates the upper and lower parts of the bellows. These valves, not shown in the drawing, are merely flat bits of board faced with soft leather covering two holes. They open upwards to admit wind, but shut down air-tight when not thus raised. There are similar ones in the bottom boards of the two feeders. The latter are worked alternately by means of a rocking lever, GG, centred on a pivot, the ends being connected by wires, FF, to the cranks at each end of the barrel, as will be explained presently.

GG are coiled springs to press down the top of the reservoir, and drive the wind out into the chest, *aa*. The wind passes up a short wind trunk, D, at the back, and is merely a square wooden pipe opening into the upper reservoir at a point in the central board, *aa*, to which its lower end is attached. The chest is thus kept full of wind at the necessary pressure to cause the pipes to speak as soon as either is opened by pulling down its pallet.

In the section it appears of necessity as if the bellows was level with the front of the chest, and the pallets just above it. In the other drawing, however, to the right hand, T is one of the pull-downs, and V a second lever or rocking shaft going to the bellows, which are placed back beyond the plane of the pull-downs. These are worked by the arrangements shown. R is a lever of iron or brass one-eighth thick or less, hinged at its centre. One end is filed to the shape shown, the other is flattened and drilled to receive the end of the pull-down which passes through it, and is screwed to take a nut below. By means of this nut the tension of the wire can be regulated with great nicety. O is the end of the barrel, which is exactly similar to those of organs, J being a part of the same seen in front, with one crank, I, fixed to the end of the axle. At W is seen the same crank with the wire which leads to the rocking shaft of the bellows, as already explained. Q shows wire staples of various lengths driven into the barrel at intervals. They are shown also at J. By means of the end of the levers R, of which one goes to each pull-down, motion is communicated to the pallets, which are opened by the action of the staples as the barrel revolves. If a staple is long, like that shown, acting on the lever, the valve of that particular pipe is held open for a long time, until in fact the staple has passed and escaped from the lever. Short notes are the result of the short staples, some of which are mere single pins, which hold the pipe open for a second only. If, instead of a steady note, one is desired with a quiver or "trill," the top of the staple, instead of being made straight and level, is indented or waved, so as partly to open and close the valve with great rapidity. A shake between two notes is made by inserting their staples, so that they may act alternately. Four pipes, each with its own row of staples running round a barrel, suffice in this way to give great variety of song. By driving one end of a staple deeper than the other, the valve it is connected with is opened very gradually, giving a note of increasing loudness; and by varying the form and size of staples, every variety of note is capable of production with great accuracy.

In the present case, the barrel, being of small size, is just as well made of a solid piece of wood. Willow, being soft, allows the pin to be driven in very easily, and is what we ourselves used. The staples were of brass wire flattened; but though we flattened ours with a hammer, we subsequently discovered that wire can be readily bought drawn flat, triangular, or square, as well as round.

A few particulars may as well be entered into here about making the barrel, which may be mysterious to such as know nothing about it. It is, however, a simple affair; and when we come to speak of our grand attempt at making an organ, it will be seen that to prick and staple a barrel does not need such an unusual amount of brains. In short, a boy's brain canister may very easily contain sufficient gumption. Suppose, for instance, there are four pipes, which have to sound at stated intervals, and for a stated period. Cover the barrel, if of mahogany, with white paper, or if of white wood, leave it as it is, and while still in the lathe, draw four lines upon it at the distances of the four levers which are to work the pull-downs and valves. Each of these circumferential lines will mark the position of a circle of pins and staples, each circle of pins acting only upon one pipe of the set. Now, whether the apparatus be an organ, a musical box, or our bird, the whole tune has to be completed in a single revolution of the barrel, and the pins and staples have to be so arranged as to produce it. The tune we ourselves required was not very long, and it certainly was not very complicated. We may write it as—twitter-twitter-twit—twit-twit—twitter—twit—t - t—titter-itter

—ter—twit-twit; but we can't express the wondrous trill, and shake, and tremolo, like or unlike a bird's song, which we contrived to elaborate.

We may consider the tune to contain exactly eight bars. It was therefore necessary now to draw eight lines along the barrel lengthwise, which we were forced to do without that convenient addition to a lathe—a dividing plate and index. This was not so difficult a feat after all, for we simply cut a strip of paper long enough to go round the barrel, and folded it into eight equal parts, and having drawn a line with a straight edge (the top of our lathe-rest) along the barrel as a starting-point, we marked the divisions at each end, and drew lines from one to the other. Each circle first drawn upon the circumference of the barrel was thus exactly divided into eight equal parts, either of which represented one bar of music. These main lines we ruled with red ink, to distinguish them from those subsequently made, which denoted lesser divisions or shorter notes. These larger spaces were subdivided by black lines into four equal parts, which sufficed as a guide to the arrangement of the pins and staples. If we had, for example, been setting an actual tune in common or four time, each space would have contained one of the notes, and if, instead of one crochet, we desired a semibreve, we had but to make the staple long enough to span two notes or two divisions. But in the present instance, we had not to compose music beyond the simple twitter-twit suitable for our bird, so that very accurate subdivision was not necessary. XY in the drawing shows a part of the upper board of the wind-chest, seen from below, except that the openings under the pallets were round to receive the pipes. The long slits are given to show at the same time the form always used in organs. We adopted the long pallet because it was on the whole easier to make than a round one. The leather which faced it formed also (as is usual) the hinge at Z. This leather appears as a black line at the top of the pallet shown at MN.

In this our first attempt we did not make the works self-acting, but led a cord from a large pulley on the axle of the barrel to a smaller one with a winch handle attached to it, by which we set the whole in motion. In a better one made at a later date we used clockwork, moved by a spring with a fan to regulate the rate, as in the striking part of an ordinary clock. The whistles were made exactly like miniature organ pipes as sketched, in the construction of which no great difficulty presented itself.

After what has been said about "the awful clock," it will not appear very mysterious to the reader how we contrived to give motion to the bird, which was set upon a pedestal of rough wood with the bark on. The pedestal being drilled first, then sawn apart lengthwise, and put together with pins after the wires concealed in it were in place.

By this means we could get at the wires readily to fix them at first, and subsequently, if they should at any time need to be altered or readjusted. The lower beak was carefully snipped off at the base, and a bit of wood glued to it so as to lengthen it inwards, and also form a lever, which moved upon a pin passed horizontally through it. This will be understood on inspection of the drawing of the bird's head: *b* is the pivot on which the lever turns, *x* the wire or silk going down to the machinery below. After the attachments are made, the skin is again carefully glued round the base of the beak. The wings were left hanging to the skin, which made the joint, and were moved in a fluttering way by a T-shaped bit of wire, the stem going down the pedestal by the side of the other wire, and the cross head supporting the wings, one on each side, and concealed by the feathers. The movement was simply to raise the wings a little, and let them fall again, which was accomplished by the end of the wire resting on the edge of a wheel with undulations round its edge, and so fitted as to turn somewhat quickly but irregularly. This gave just the slight flutter required. We found it indeed quite possible to dispense with one wire in the pedestal, by attaching the end of the thin lever, which was glued to the beak, to the wire which moved the wings. The same wheel moving both at the same moment, gave an appearance of simultaneous muscular action very true to nature.

In all these automatas, of which we made a good many from time to time, we found that attention was much needed in producing similar movements at irregular fitful intervals. When this is skilfully accomplished there is less appearance of mechanical work, because nature works just with what we may call irregular regularity, and the failure even in such a collection as that of Madame Tussaud's in giving a more natural appearance, lies in the fact that the automatic movements are too regularly performed. They suggest clockwork the moment we look at them.

The fluttering of the wings of our bird being dependent, as stated, upon a wheel with serrated or irregularly-notched edge, we had only to make each part as different in outline from any other as we could, to secure the variable motions of the wings and beak. But we even added to this irregularity of movement, in the following manner:—

We drove the serrated wheel by a cord from a pulley on the axis of the barrel, but we made this pulley slightly eccentric, so that the cord was not always equally tight. The result was, that when it was not strained sufficiently to drive the serrated wheel, the latter was still for a few seconds, until the eccentric pulley revolved far enough to enable it to draw the cord tight, when it of course started again. It was just so arranged as regards eccentricity that it made the cord tight enough to work for the greater part of its revolution, and only slackened it for about one-sixth part, during which the wings and beak when worked together ceased to move; and when the latter was the case, we of course took care that the warbling should also cease, by the absence of pins in the barrel at that particular part.

In making this automaton without having any opportunity of knowing precisely the best way of doing it, we had to work literally note by note, without any other guide than the ear, aided by some recollection of the successive notes of the bird we hoped to imitate. By the help of a piano, however, on which to try the various modulations, and aided still further by a good-natured sister, who had the patience of Job, we succeeded, and fully accomplished our self-imposed task, and mighty proud we were too of our first warbler.

Chapter VI.

OUR FIRST ORGAN.

THE success of our songster, described in the last chapter, made us ambitious to try our hands upon an organ. But we had to moderate this ambition, and be content with a small affair, on account of the cost of material necessary to be incurred for a large instrument. We were therefore limited to four octaves of notes, but with one additional stop we could somewhat extend the scale, and we determined some day to try our skill in the fabrication of a much better "kist o' whistles," as amateurs' organs have been ignominiously named.

In our youth, alas! there were none of the pleasant and instructive mechanical works now in use. The "English Mechanic" was not even born, and the "Encyclopædia Britannica" was our sole teacher of the mysteries of an organ's inside.

We might have much simplified matters had we not aspired to the one stop, which entailed, in addition to a wind-chest, a sound-board—a part far more complicated than its name would indicate, as it is not a board at all, but a shallow box with slides to cut off or open the various rows of pipes as may be required. In large instruments there are many of these sound-boards, and the pipes are numbered by thousands. In the organ at the Albert Hall, Kensington, there are rows and rows of stops one over the other, but all within reach and command of the organist.

There is not, after all, any very great difficulty in organ-building. It is merely joiner's work well and soundly done. But the pipes offer difficulties peculiar to themselves. They may simply sound a *noise*, or a note of music distinct and decided. Nothing but practice will enable any one to make a thoroughly good set of pipes, even in wood, and metal ones are hardly within the province of boys, or indeed of the majority of their elders; but a boy may make pipes sufficiently well to give a very fair tone, and may construct a small organ which will give him and others both amusement and pleasure.

The prime mover, as it may be called, is of course wind supplied to the pipes from the bellows, which are of the double kind, like those of a blacksmith, but always made of an oblong shape, and generally occupying the lower part of the instrument next the floor. Sometimes, however, the bellows are conveniently placed elsewhere, and are set on end instead of lying horizontally. From them the wind in a high pressure state passes up the wind trunk, a wooden pipe of square or oblong section, which is often provided with a valve at one side opening outwards, and kept close by a spring. This is to provide against any sudden forcible impulse of the air by the fault of the bellows blower, as a sudden gust opens the valve and allows of the escape into the air of the wind in its compressed state, so that only a steady and uniform blast is conveyed into the wind-chest, and thence through the channels in the sounding-board to the pipes, by means of the slides and keys. Plenty of wind steadily supplied is of the first necessity, and if the bellows are too small, the instrument can never prove of much practical value, but excess of wind is easily got rid of by a simple plan of escape-valve, which acts as soon as the reservoir rises to an undue height.

Turning our attention, therefore, first to the bellows, they are found to consist of three boards connected together on all sides by an envelope or casing of leather.

In the lower and middle boards are flap valves—pieces of wood covered with leather and hinged to open upwards, if the bellows are to take a horizontal position. The hinge is made by nailing down the leather which forms the face of the valve, and which is cut long enough to permit of its being thus used. In double bellows the middle board is fixed to the framing, and the lower one is worked up and down by the lever or rocking staff. As it falls, air rushes through the valve, but cannot again escape, and is driven by the raising of the lower board through the middle valve into the upper part of the bellows, or reservoir, as it is called in an organ. The upper board forming the top of this reservoir is pressed down by springs or weights, and drives the wind out into the wind-chest through a pipe or trunk, generally of wood, which opens into the reservoir just above the central board to which it is fixed.

Bellows, however, made in this way would be apt to rise and fall very irregularly, and would not be compact when closed and empty. Between the several boards, therefore, alluded to, there are oblong frames of wood, to the edges of which the leather is nailed; these frames being the same size as the boards. These keep the leather extended equally on all four sides, and rise and fall as the bellows are alternately expanded and closed. In addition to these, there are also crossed guides hinged by a pivot to the corners of the boards, and also pinned together where they cross, which compel the boards to rise horizontally and equally.

The boards and frames are generally of ash or elm, which are tough durable woods, not liable to split by driving the nails to attach the leather. They should be dry and well seasoned to prevent the risk of warping, which, however, would not be so fatal in the bellows as to the wind-chest and other parts. Any soft and pliable skin will do for the bellows of a small organ. That called basil is very general, and is prepared in a particular way for the special work.

It may, however, be mentioned here, that in a large church organ of modern construction, the bellows are not made like house or smith's bellows; there are the three main boards, but the intermediate part is not wholly of leather, but of boards with leather joints, enabling them to fold closely together and to rise evenly on all sides. They are made, in fact, like the bellows of an ordinary Accordion, except that in that instrument the thin boards or *ribs* are of card instead of wood. They require a good deal of careful cutting and fitting, but are vastly superior to bellows wholly made of leather, and are therefore now universally adopted. Made simply of three boards with intermediate stretching-frames, there is the advantage of not requiring corner gussets and such-like details, which are so difficult to cut and fit properly; but, on the other hand, more leather is needed, making an increase of cost, and the finished work is not so neat. Both methods are given, however, here, for we used both, and I think with about equal success. In the ensuing description, however, the orthodox plan will be described.

For the wind-chest we used deal, straight-grained, clean pine, as dry as we could obtain; and never did we find greater need of sharp, finely-set planes to square up and render it true in all directions. By this time, however, we were tolerably versed in the practice of joinery, and had satisfactorily passed that Pons Asinorum of amateurs, the art of planing. The pipes were also of deal, with the exception of the caps and blocks, hereafter to be described, which were made of mahogany. The lower conical tubes, which fitted into the holes of the sound-board, however, we made of beech, as being easy to turn, and already part of our stock-in-trade. The keys were not altogether home-made, for we managed to purchase an old worn-out piano of ancient date, whose keys we modified to suit our purpose. They were rather narrow, and the ivory finger-plates no longer of the delicate colour which gives such beauty to the keyboard of modern instruments. They nevertheless served us very well, and saved us a great deal of difficult work.

The four octaves of keys occupied a length of two feet, and consisted of forty-nine notes, beginning and ending with C natural. From this we took our various dimensions. Forty-nine notes with two stops required ninety-eight pipes, so that we certainly had our hands full of work, as our heads were full of ambition and of hope. The organ was, in fact, of very fair and serviceable size, and, well handled, was capable of discoursing much music, despite many slight defects peculiar to the work of youthful amateurs.

As the keyboard required a width or length of two feet, and an organ pipe of wood, being wider than a single key, would need more room, we saw that we should hardly be safe with a sound-board on which these pipes would be placed, of less than three feet, even if we put a few of the large pipes in front, and carried the wind to them by leaden feeders. We therefore made it four feet, so as to err, if at all, on the safe side. The bellows might, we considered, be less, and we made them three feet by eighteen inches, which proved sufficient.

The annexed illustrations will show the relations of wind-chest and sound-board with the mechanism of the stops, by which one or more rows of pipes may be used at the discretion of the player.

In fig. 11, the sound-board is seen partly in section. It consists of a strong shallow box, divided into channels by bars planed very true, the ends of these being let into the sides of the chest. Great care is taken to render the channels thus formed perfectly air-tight, even against

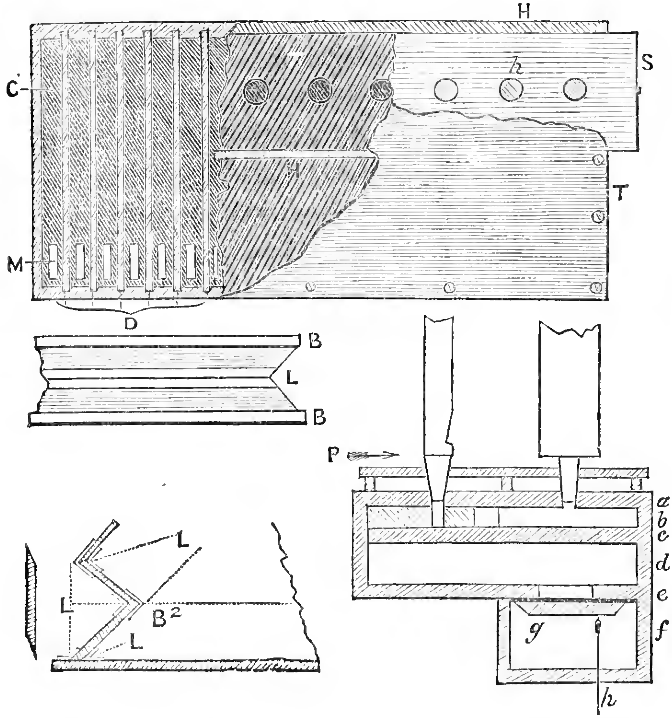

Fig. 11.
C, Channels. *T*, Top of lower part. S, Slide. T, Top board. D, Divisions or bars. M, Holes in lowest board.

the full pressure of wind that can be brought into them by the bellows. There must be as many of these channels as keys, each answering to a single note. It may be explained at once in this place, that the reason the channels are needed is, that every single note of an organ may have several pipes of wood or metal, of which, when a key is pressed, one or more may sound as may be desired. Taking the first channel, therefore, of our organ, all the pipes standing over it were tuned to C. We had but *two* pipes to each note, but if the sound-board were wide enough, it is plain that several might be ranged over the same channel. This sound-board being so far completed, the upper board is glued and screwed on, but generally the whole of the *bottom* board is not attached, a part of the bars appearing underneath until the pallets are put on, and the wind-chest, which covers and conceals them. In our small organ, however, we covered the whole of the bottom of the bars as well as the top, so that none of the inside arrangements were visible.

Before screwing on the top and bottom, we took care to glue the edges of all the bars, as well as those which formed the outside or frame, and while the glue was hot we put on the boards, and drove the screws home quickly, making all perfectly wind-proof.

We now had to arrange the stop, and our method of doing so will explain that adopted in large organs.

The object of a stop is to shut off any row of pipes, and therefore it has to act upon all the channels at the same time. Suppose a hole to be bored, H, over each channel, through which the wind would pass if a key were pressed down; and suppose a row of pipes, properly tuned, placed over such hole, any of these might be sounded at pleasure. Let the pipes be now removed, and a long strip of board, S, laid along over the holes, with holes bored in it to match those below. It is evident that a little movement of this board lengthwise would close all the holes simultaneously, so that if the pipes stood over the slide, not one of them would sound unless the slide were again shifted, so as to make the holes coincide as before. One such slide is arranged for each row of pipes, and is called a stop, and named by the title given to the pipes in that row, whether of wood or metal.

The slides are arranged thus:—Strips of clean deal or mahogany, HH, are glued down at distances equal to the width of the slides, and of exactly their thickness, reaching from end to end lengthwise. These are the guide bars between which the slides move. The slides themselves are preferably made of well-seasoned mahogany, as not being liable to warp and twist, because it is absolutely necessary that they should move smoothly and easily, and without shake. Upon the edges of these bars, which are from half an inch to an inch thick, or in large organs even more, are glued strips of brown paper, on which rests the top board, which is bored at the same time as the top of the sound-board and slide, to receive the ends of the pipes. The paper raises this board very slightly, just so much as to let the slides free. The first guide strips are glued on flush with the top edge of the sound-board, so that when the top board is on, and screwed down, it forms with the top of the sound-board another very shallow box divided by the guide strips into long channels, but wider channels than those before described. In fact, as regards the shallowness of this part, it is of course dependent on the thickness of the slides and the guide strips between them, and we found three-eighth stuff amply sufficient for the purpose, making the depth and thickness of the strips equal.

Dividing the total length of the sound-board into eighths of an inch, in order the better to find out the width we could afford to each channel, and taking three-eighths as the thickness of the strips by which to divide it into the several compartments, we found that we had 288 eighths, which would give us forty-nine divisions of more than five-eighths, but less than six-eighths each. These would include the strips and the channels, so that if these were equal, we should have, roughly speaking, three-eighth strips and three-eighth channels. But as some of the large pipes needed more wind than such small channels seemed likely to carry to them, we made some fully six-eighths, and others only quarter, and also used quarter stuff instead of three-eighths for a great part of the distance. The outside of the framework was, however, all of inch stuff, as this had to receive the screws by which the top and bottom were fastened on.

Oblong holes, or two holes a little distance apart, were now necessary, as at M, in the front part of the lower board of the sound-board communicating with the several channels, over each of which holes the pallet had to be fitted. In large organs the bottom board would have ended, as shown, towards the right hand, so as to expose the bottom of the bars, which would of course have answered as well, the pallets being fitted to cover the spaces between the bars, and prevent wind from entering the channels. We thought it would be easier to work in the other way.

At P is a section across the centre of the sound-board and wind-chest, which, with the previous description and illustrations, will make the whole arrangements quite clear. Here *a* will represent the upper board of the sound-board, above which is the rack for pipes—a board supported on short pillars, and bored to fit the turned feet of the pipes and keep them upright. The white space, *b*, is that of the slides or stop-boards; *c*, the upper board of the sound-board before the addition of the guides and slides; *d*, one of the wind channels; and *e* the bottom board. Below this, which carries the row of pallets, *g*, is fixed an oblong box running the whole length of the sound-board, and occupying width enough to allow the action of the pallets to take place within it. It is marked *f*, and is called the wind-chest. It receives its wind from the wind-trunk rising from the bellows, which may open into it at either end or at the back, as most convenient. Ours was at the left or bass end of the instrument. The wire pull-down is seen at *h*, which is acted on by the key direct in a small instrument.

It will be noticed, in this description of our organ, that I frequently generalise, in order, while describing the humble instrument which we contrived to make, to give the reader some insight into the construction of such organs as are made for our churches by modern builders, the object being to make our little volume as useful as possible, even to some few who may condescend to peruse its contents, though the jacket has given place to coat-tails and other abominations of an adult's dress.

We must now return to the bellows, a small portion of which is illustrated here at BLB, and also at B2. The first is a side view, showing the wood and leather as seen when the bellows are partially distended; the latter, a section showing the way in which the joints are constructed. In the first the leather is left white, and in both drawings it is marked L. The sectional view shows that the leather is placed inside as well as outside the boards, the latter being bevelled off each way as at E, to allow the boards to fold together as they ought to do.

It is now necessary to enter into the mystery of pipes, both wood and metal. Of the latter we should certainly have made a great mess, for they can hardly be made by amateurs a great deal more practised than we were in organ construction. We made our second row, however, in a way of our own, and gave it the name of Hautboy, as being a kind of reed-stop, though I doubt if ever before or since a similar one has been made. An organ pipe is (omitting reed pipes) merely a well-made whistle on a large scale, although, perhaps, the latter phrase is scarcely correct, since the smaller ones are really very small, not much bigger than a metal penholder; but, on the other hand, some of the wooden ones are as much as thirty-two feet in length, and most organs contain sixteen-feet pipes, which are certainly Goliaths among whistles.

Before setting to work upon the pipes, we found it necessary to make a sort of scale or guage, which I fear was at best a very imperfect and incorrect one; but, as stated before, we had to hammer ideas out of our own brains, and to work with very scanty information. After all, however, it strikes me that nothing is ultimately lost by a lad having to gain information by deep thought and experiment. Gained in this way, it is generally of a durable character, which is not the case with the superficial information which is the result of the modern system of cram.

We began quite at haphazard, by making a wooden pipe to represent the middle C of a pianoforte, or what I believe organ-builders call tenor C. I cannot recollect what guided us in making this pipe four feet six inches long by two inches each way, but possibly we asked some one who was supposed to know all about it. However, when we tried it with C on the piano, we found it about two full notes lower than it ought to have been, and we cut off first one inch, and then another, and found it getting nearer to the required tone. We then reduced it by little and little to four feet, and after some additional manipulation about the mouth, raising and lowering the block, which was fitted but not glued on tightly, we managed to get the note correct, if not exactly of good quality; but then we only tried it with the breath, and also the kitchen bellows. This was our sample of *stopped* diapason; that is to say, it was not left open, but was closed with a wooden plug, without which it would, as we found by experiment, give a note an octave lower. The latter would be called in organ phraseology an open diapason, and in a large instrument the lower part of this stop would probably be of wood, and the upper octaves of metal. The principle of the pipes would be exactly the same, as the sound is caused by the wind striking against the thin edge of the lip, and setting a column of air in more or less rapid vibration in the body of the pipe, or *flue*, as it is technically called.

We found that for each note about the middle of the scale, the length of the pipes must diminish very nearly three inches; but when the large pipes were reached, a difference required to be made of four or five inches. We heard afterwards, and subsequently proved, as usual, by actual experiment, that great variety of tone could be produced by varying the form of the flue. Thus a conical pipe did not sound like one with parallel sides, nor did a pipe with the largest part of such cone at the top sound like one with the largest part close to the lip. Again, we found it made a difference whether the thin edge of the lip was formed by bevelling off the pipe from the outside or the inside, and that the formation of the cap which covered or provided a channel for the wind also tended to modify the tone.

The toning or voicing of pipes is indeed a very delicate matter. Wood can be voiced to speak like metal, and metal to imitate wood so closely as to defy detection by any but the most critical and experienced ear. It is highly necessary that this skill in voicing, however, should be attained by those who hope to excel in organ-building, because it is requisite that precisely the same quality of tone should run through all the octaves of any particular stops. It is not sufficient that each note should be accurate in tune or pitch, but it must match the rest in what is called "timbre." A reedy note, for instance, would be intolerable to a musical ear if it occurred in the same stop which gave generally a flute-like tone; and yet a skilful organ-builder can, if he choose, make the same shaped pipe give the two qualities of tone merely by the act of voicing it—*i.e.*, regulating the force and direction in which the wind shall strike upon the thin edge or lip of the pipe.

I shall presently have to say a few words upon the secrets of voicing, but it was a performance we had never even heard of. We made our pipes in the plain and simple manner which will be described here, and if they were not of first-class quality of tone, they spoke evenly, and were in good tune; and this to boys like ourselves was a sufficient triumph for a first attempt.

It would occupy a larger volume than the present, to detail the particular forms of pipes used in the present day in organs of large size and variety of tone. It will be necessary to confine our remarks to the two kinds denominated "flute" and "reed" pipes, and of these sections and drawings are here annexed. Flute pipes, whether stopped—*i.e.*, fitted at the top or open end with a plug, which always raises the note of any given length of pipe an octave—or open, consist of a flue, a block with its air space, and a cap, to which must be added a foot, which is the turned pipe on which the larger one stands, and which carries to it the wind from the sound-board.

I often smile now at the labour it cost us to make pipes, the mystery a pipe was to our minds, and the many failures for want of a little advice by which we were compelled to purchase our experience. Of course I am now writing as if we found no such difficulties, and merely stating rather how we subsequently and rightly made the pipes, after obtaining a pattern one and a little kindly-imparted instruction from a builder.

The block, which is the first part to be considered, is merely, as the name indicates, a solid squared-up piece of wood, generally mahogany. To give the sizes of a standard pipe of this kind, the block A, fig. 12, is two inches long, one and a half wide, and one inch thick; and it has a piece cut out of it as shown, which it is easy to do with a fine saw and narrow chisel. This block

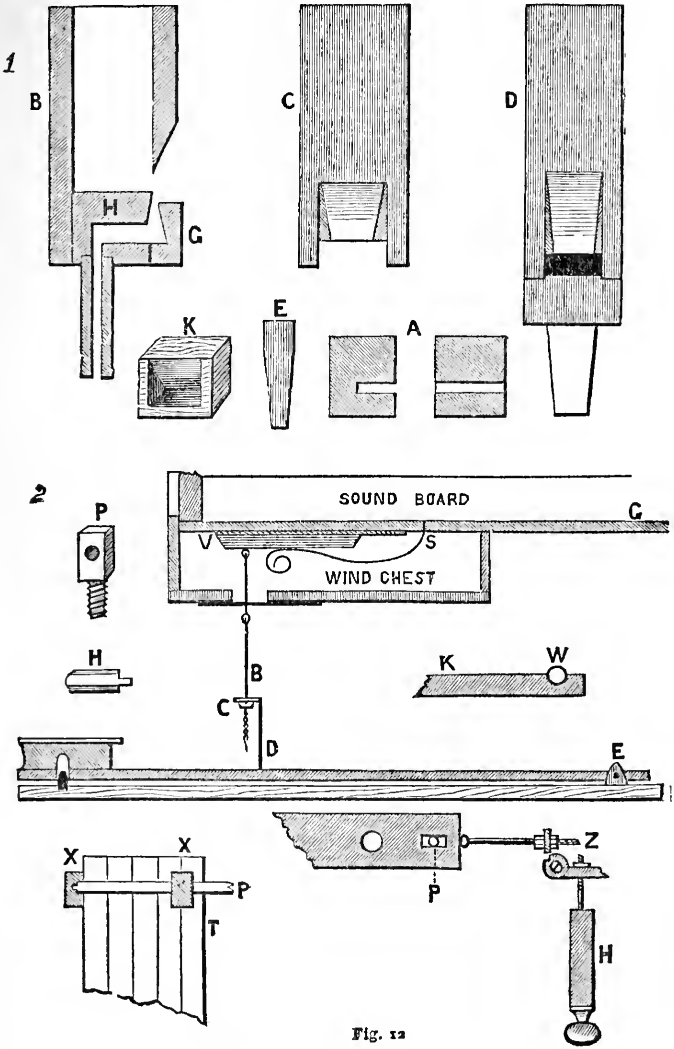

Fig. 12

must be planed true upon all sides, or the pipe made upon it will evidently be out of shape and useless.

B is a section of the pipe, D a front view, C the front of the upper part alone above the block, E the foot, or conical pipe on which the whole stands, and which is seen in section in the first figure, in which the block is also plainly seen at H. G is the cap that fits on in front, and is so cut away on the inside as to cause the wind to strike on the sharp edge or lip above it, which lip is made by cutting back the lower end of the front board, C. This cap is shown in perspective at K, where its form may be very easily understood. In the section of the pipe complete, B, the course of the wind can be traced without difficulty. It may readily be imagined that by leaving the mouth of the pipe more or less open, enlarging or diminishing the wind channel, adding to or diminishing the width of the pipe in proportion to its length, and otherwise modifying its dimensions, great variety of tone can be obtained; and after pipes are finished, the operation of *voicing* is carried out, which consists in opening out or diminishing the mouth, nicking the edge of the front board, and in various ways regulating the size and form of the lip, so as to cause it to give more purity of tone. So readily are variations of tone attained by voicing and modifying these pipes, that an organ may have several stops or registers of wood—

i.e., several sets of wooden pipes—of which no two shall sound the least alike. A great deal depends on the shape of the flue or body of the pipe, which, of course, may be made, as here, with parallel sides, or with the boards formed to produce a more or less conical shape, and then again, the widest part may be at the top or below.

As we did not attempt to make any metal pipes, I shall not describe them further than to say, that the flute or diapasons are made on precisely the same principle as those which I have detailed here, only no block is used, but the foot is continued to the mouth, and so made as practically to serve instead of a block, it being so arranged as to throw the stream of air against the lip. This lip is formed by bending the metal inwards, as may be seen any day in a penny tin whistle. These metal pipes are of all imaginable shapes as regards the flue, but the chief distinction recognised is, that some are reed pipes and others diapasons. This reed is a vibrating tongue of metal, which is tuned by a wire so arranged as to lengthen or shorten at pleasure the free end of the reed. We made a sort of reed pipe ourselves of wood, but it was a very troublesome job, and not very satisfactory when done.

For this purpose we made our square flue pipe as before, but on the top of the block we fixed the reeds of an old accordion, one in each pipe, so far as they would go; and having soon exhausted our stock, we made the rest of brass, hammered to give it hardness and spring. In fixing these, we had to hollow out the block, and so shape it as to enable the reed to project downwards, because the wind must strike on this projecting side. We could not therefore manage without first riveting the tongues to a bit of thin iron, which we then fixed with small screws to the block. We tried various modifications of the plan, fixing similar free reeds inside the front board of the flue itself, and also in some other positions. We hoped to get a tone like a reed instrument, hautboy, or clarionet, for instance, but were only partially successful.

In after years, when time and funds permitted us to launch out somewhat more freely in our mechanical work, we found the experience of our younger days, and especially the many blunders and failures of those days, of great value; and our early attempts at organ-building developed, by practice, into a facility in work of this nature which enabled us to build several very fair organs, which we sold at a good profit. But I think none of these grander and more complete instruments gave us half the pleasure which we derived from that which we have been describing.

The connection of the keys with the valves is, as may be supposed, almost precisely like that described in our mechanical bird in the last chapter. It is illustrated in fig. 13. A is the key, pivoted at E, where there is a bit of brass between each key rising from a fixed board underneath them. This brass is merely a bit of sheet metal bent sharply at right angles like the letter L, so as to fasten to the board at the bottom, and receive a wire through the upright part; or it may be—for we subsequently so arranged it—dispensed with, and replaced by a single brass rod lying above all the keys in a deep notch in their upper part, as seen at K in section, and at RXX, as seen from above. The rod is not absolutely continuous the whole length of the keyboard, as it was difficult to get it straight of such length, but we made it in three pieces, placing blocks, P, to take the ends of each as shown at XX; the keys on each side being cut away where they occurred. The ends of each length were made smaller, as at H, this reduced part entering holes in the blocks. We found it necessary to put a second row of the steady pins, F, about the middle of each key, which, thus arranged, worked very freely and pleasantly. It will be noticed that the pull-down wires which open the pallets, V, of the sound-board pass at C through a piece of bent brass, and that they are fixed by a nut; this enables them to be strained to exactly the proper degree of tension, which is of importance, as they should be just so tight as to open the valve when the key is lightly touched. The black line under the wind-chest represents a plate of brass attached to allow the wires to pass through nicely-drilled holes in it. This is a sufficiently air-tight arrangement, while at the same time the wires work more freely than they would in a piece of wood.

There is not much more in the way of detail that needs illustration, as there is no difficulty connected with the bellows handle or leverage, by which the one stop was pulled out and pushed in. There was just a bell-cranked shaped piece of wood, Z, turning on a centre, and attached on one arm by a link to the slider, and by the other arm to the stop-drawer, H, a squared bit of mahogany with a turned handle. The method of attachment by screwed wires and nuts allows sufficient play to the parts to permit the slide and stop to move in a right line, instead of partaking of the circular motion of the ends of the crank. By an oversight the part A of the key has been drawn as if standing considerably above the rest of the key. This is only the case with the black keys. The rest are level, but broader at the end A. The set were, in fact, as stated, originally made for a pianoforte. The wire *z* of the stops must not be supposed to be merely a bit of bell-wire, but is stiff enough to push back the stop as well as to pull it out. This will only answer for a very light slide, for other mahogany rods must be used. Rollers and trackers are also necessary in organs, in which the keys are not opposite their respective pipes, but we managed our small organ without them.

Although in some of the details—as, for instance, the rollers just alluded to—organs are constructed differently to that here described, it has seemed better to stick as far as possible to the original plan of our little book—to show how a pair of lads, using their own talents in their own way, triumphed over the difficulties met with, and succeeded in building an organ of small size but of fair tone, and capable of being played on with satisfaction to others as well as to themselves. In trying our hands, subsequently, at a larger concern, we altered many details which experience showed us needed improvement, and followed, so far as we were able, the plan of professional builders.

In respect of the last sentence there is a lesson to be learned by experience. Boys and amateurs generally are somewhat inclined to follow their own devices, under the impression that their way of doing things is at least as good, if not better, than that of professionals. Let them be assured that nine times out of ten they are wrong; but there is nothing like experience to teach them this. We boys (like other boys) were tolerably full of self-conceit, but we very often failed utterly, and still more often partially, in our attempts at the various handicrafts, for want of knowledge and information which we would not condescend to ask, and after many tiresome experiments, due to our conceit, we always discovered that we had set about our task in an unworkmanlike manner, and we found ourselves at last working in the very way in which we should have worked had we at the first gone to some one who had been trained to that work, and condescended to ask him to show us how to do it. A civil request of the kind is, moreover, seldom, if ever, refused to a lad by a professional.

Chapter VII.

OUR HOUSE

WE now began, like lads whose brains were somewhat like the troubled sea, to hanker after a job of a heavier class, and the circumstances which led to our choice were as follows :—

We had both left school, and having by no means wasted our time, we were now to have a year or two at home under a private tutor, who was thoughtfully selected for us, not for his scholarly attainments alone, but for his predilection for mechanical and scientific pursuits. A Cambridge graduate in mathematical honours, his special task was to instruct us in the *theory* of engineering, which his own knowledge of the practical details enabled him to do with more than ordinary facility, because if we failed to lay hold of any mechanical law, he was often able by a simple experiment to explain it to us in a way that at once fixed it indelibly upon our minds.

We had, of course, left our old workshop behind us, and not without a parting sigh of regret. I remember well how we went to pay a last visit to the scene of our many happy labours, and removing the old notice boards of "No admittance" and "Beware of the bull-dog," we substituted another, which stated that "the carpenter's shop and engineering establishment was permanently removed to larger premises."

These larger premises consisted of an orchard within the parental estate, in which we now proposed to erect a new workshop. This, however, was to be a combination of shop and study, as we fancied it would assist our mental toil if it was carried on in close proximity to the scene of our various handiworks. For this purpose we determined to build a workshop with a study opening out of it, and by our father's kind liberality we were enabled to procure the raw material suited to our requirements. The only stipulation made was, that we should construct the building in a workmanlike manner, and not so as to be an unsightly object upon the premises. As I was now nearly nineteen, and my brother seventeen years of age, both at that time, moreover, in robust health, the actual labour in prospect did not terrify us. We were early risers and kept regular hours, which of all things specially adds time to one's days. Desultory work is, as we had seen with some of our companions, the greatest bane to success; and the surest way to accomplish life's various tasks in a thoroughly satisfactory manner is to set apart certain hours for each of them. We began our day, as boys ought to begin, by a quiet half-hour with our Heavenly Father, then we studied till the breakfast-bell sounded punctually at eight. We then had an hour at our work, generally putting things straight, grinding and sharpening tools, and from ten till one we had a grind ourselves with our tutor. After early dinner we set to work upon our house, and generally kept at it till six, when we had tea. In the winter months we had to arrange our time differently, but always learned the value of order and discipline, acquired partly at school, and partly under the kind but strict rule of a most worthy father. As a Navy man, he had himself learned to obey before he learned to command others, and our home life was to no small extent modelled on that of a man-of-war, nor, perhaps, can a better model be found anywhere.

The foundations of our house were brick, and these were carried up all round two feet above the surface of the ground. This work we might have had done for us, but as we were intended for engineers, and had not yet determined to what department of that profession we should eventually turn, we thought a little practical masonry would at any rate do no harm, but rather give us an insight into details of work that we might some day have to superintend.

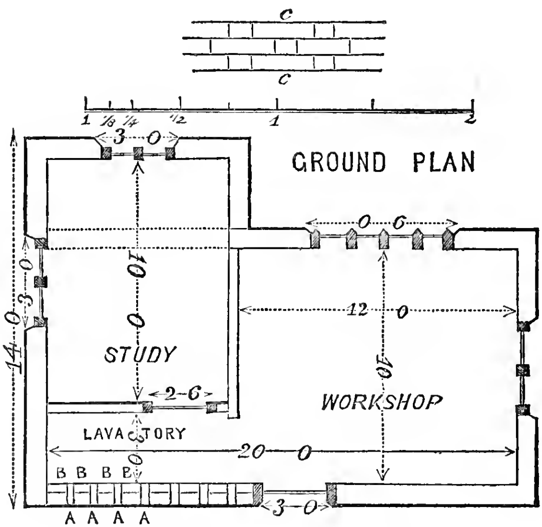

Fig. 13.

Fig. 13 is the ground-plan. It will be seen that, although we by no means despised learning, we gave the workshop the place of honour as to dimensions, making it twelve feet by ten, whereas the study was only ten by eight. But out of the latter we cut off a space of three feet for a lavatory, otherwise it would have been larger. This lavatory was an essential, as hand-washing cannot be very well omitted after workshop operations, unless grimy books are desirable. We had, however, no door between our workshop and lavatory, which in fact formed a lobby, the study opening out of it. The workshop was well lighted by two windows in adjoining walls, one being six feet long, the other three. The first of these was two feet six high, the latter two feet. The details of both will be found farther on. The study windows were both two feet high by three feet wide. We used nine-inch brickwork—*i.e.*, our wall was one brick thick.

The bricks always need to be so laid as to bond together in a proper manner; the joints of one row must never coincide with those of the one next above or below. In one part of the front wall is illustrated the common manner of laying one row of bricks of a nine-inch wall, and in that just above it the headers A and stretchers B would lie in the opposite direction; thus bringing the centre of a brick over a joint AA; this, it will be seen, will tie together the inner and outer faces of such a wall, which might otherwise easily split asunder in the central line or joint of the stretchers laid longitudinally. This is called Flemish bond, and gives to the front of the wall the appearance so generally seen—the long and short sides of the bricks alternating. A small portion of the face of such a wall is shown at CC, and will be recognised as the more common form.

English bond is made differently. A row of headers is laid, and on them a row of stretchers, and so on alternately the whole height of the wall. In this case, the front face shows apparently alternate rows of short and long bricks, which certainly does not look so well. It may happen that the total length of a wall is such that nine-inch bricks, inclusive of joints, will not exactly reach from end to end. There must, consequently, be somewhere inserted half or quarter bricks. The joints are, however, always made to *break*, as it is called, or the whole would fail to be of that substantial character so necessary. It is specially an object with a bricklayer to make the joints overlap at the corners, so as to bond the four walls of a building thoroughly together, each serving as a support or buttress to the other. Thus if the first tier ends at the corner with two stretchers, he will lay a single stretcher only on the face of the wall, but behind it, instead of the second, he will lay the ends of two stretchers of the wall at right angles to it, thus turning the corner, and this will also have the effect of getting the bricks of that wall in proper order. The length of a brick is nine inches, the width four and a half, so that two headers exactly cover the two stretchers beneath it. But it will be found upon trial that a second row will not break joint if a pair of headers are laid on a pair of stretchers, simply as described, although this is the way to build such a wall, but somewhere a brick must be split in each row lengthwise, which will bring all the joints right for that row or layer. In the same way in walls of a brick and a half thick—*i.e.*, one laid flat as a header, and one laid flat as a stretcher alongside of it—it becomes necessary very often to cut a brick either across or lengthwise to bring the joints right; and the necessity for window and doorways, which would interfere with the regular bonding, may compel two headers to take the place of a header and stretcher, or *vice versâ*. A bricklayer used to his work never hesitates, but sees exactly where he can best place his half bricks, so as not to interfere with the general appearance of his work, but we had many a consultation on that score, as amateur masons do in such cases.

We found the best way of learning the art, which, after all, is very simple, was to draw plans to scale, making the bricks the exact relative size, so as to find out whether they would bond; and we also made some of wood also to scale, like those of a box of child's bricks, and with these we built up walls of various kinds of bond, so that we soon had the secrets of bricklaying at our fingers-ends. We also learned a good deal of plan-drawing by thus putting things down on paper, and drawing everything properly to scale, a method we recommend to all young mechanics.

We carried the foundation, as I have said, two feet above ground, and below we dug out our trenches one foot deep, which brought four courses underground. We had good, dry, and firm loam to deal with, and below was gravel, so we found this to be quite deep enough to secure the stability of a small light building. There were eight courses above ground, each brick being three inches thick. When I say two feet above ground, I mean, therefore, eight courses, but with the mortar it was a little higher.

The worst part of bricklaying was, we found, the effect which lime has upon the skin of the hands, which became dry, and would have chapped if we had had more of the work to do. This results from what chemists call the affinity of lime for water, which it absorbs. Thus all the natural perspiration, which keeps the hands moist and soft, is seized upon by the lime, leaving the skin in a perfectly dry and inelastic condition.

Nothing shows this absorbent property of quicklime more than the process called slaking it to make mortar.

Quicklime is carbonate of lime burnt. This substance occurs in various forms in large quantities in nature.

Chalk, marble, limestone, oyster shells, and indeed most shells, with those beautiful stalactites found in caves in Derbyshire and elsewhere, are all carbonate of lime in varied forms. Ordinary limestone, forming hills and rocks, is the substance most commonly used for making quicklime, as it can be procured in almost all parts of the country. This is broken into large lumps and burnt in kilns, which are often holes dug in the side of a hill and lined with firebrick; and sometimes are built wholly above ground, but the first is most convenient, as the stone must be wheeled to the top or mouth and thrown in. When thoroughly burnt, the lime is drawn out at a hole made for the purpose at the bottom of the kiln.

The heat drives off the carbonic acid, or carbonic anhydride, as it is now often called, in the form of gas, which is fatal to animal life. It sometimes happens that the lime-burners fall asleep too near the mouth of their kilns, and are quickly sent to sleep by the gas, and perhaps burned to death without awaking. It is a very heavy gas, and escapes, therefore, but slowly into the air above it. After this gas is driven off, the limestone is found to have acquired new properties, which, however, will not last long if it is left exposed to the air, as it will again pick up carbonic acid and become what it was before—viz., carbonate of lime.

In its new state it is called caustic lime, because it will burn and destroy animal and vegetable matter, and in this state it has the peculiar property of so entirely absorbing water as to dry it, so to speak; for if a bucket of water is thrown on a heap of quicklime, the latter heats very much, steaming and smoking, and then all at once falls to pieces as a perfectly dry powder. It is in this state that it is used by the mason, being called slaked or slacked lime, and mixed with sand or road grit to make mortar. We had seen this operation very often, but until we ourselves performed it we had thought little about the why and wherefore. Now, however, our curiosity was roused, and our tutor kindly gave us the information here recorded, with much more about this and other gases which we cannot set down in these pages, as we must go on with the details of our house-building.

The shallow flat-bottomed trench dug out to receive the foundations of course marked out the outline of the building. We had taken all possible care, therefore, to make the sides truly square to the ends. The partition between the workshop and study we intended to make entirely of wood, and here we only gave the wall half the thickness, building it with single stretchers, the joints overlapping as before. At the doorway the wall was carried but one course of bricks above the level of the ground, to receive the cill, a piece of oak, into which the doorposts were mortised ; but where windows occurred we built up to the normal height, as the bottom of none of these was to be less than three feet from the ground. Having thus raised the foundations to the required height, we laid upon them the main timbers or wall-plates, into which all the chief uprights were to be mortised. These were seven inches wide and six thick, and all the mortise holes were marked and cut before putting them in place upon the walls. Where they met at the corners, they were half lapped into each other as seen at L, fig. 14.

This drawing also shows the details of the timber framing and boarding of the back of the house, in which was the outer door. BB are the wall-plates last described. They are bevelled off at the upper face all round to throw off the rain. The uprights at the angles are six inches square, the rest, including doorposts, four inches by three. The wall-plates are laid flush with the wall on the outside, so that a ledge of brickwork remains of two inches on the inside. The uprights are placed so as to be flush with the top edge of the bevelled part, which is cut back one inch. The corners of the wall plates are pinned together by the tenons of the corner uprights, which go through the upper half lap into but not through the under one. The posts are not pinned sideways, but are held by the pinning of the uprights, CC, so as not to weaken the half lap joint

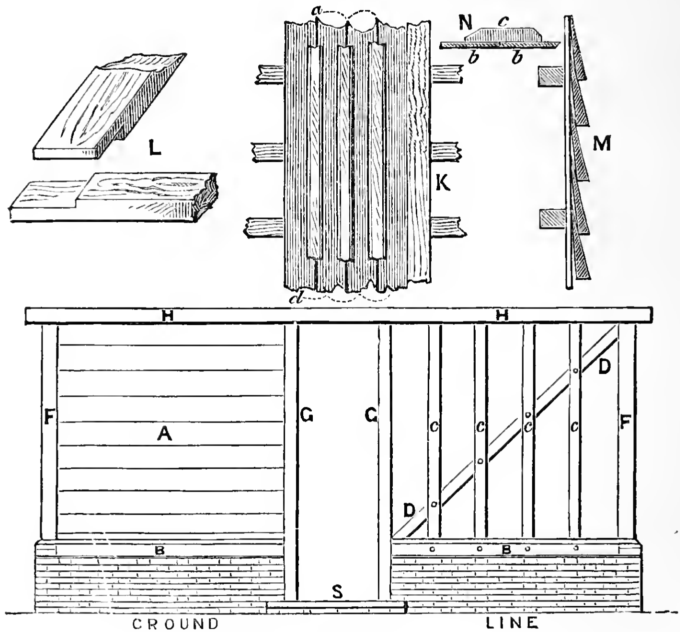

Fig. 14.—House Construction.

unnecessarily. All the uprights are mortised into the upper wall-plate, HH, which extends six inches on each side to take the outer rafter, and form eaves overhanging the end walls.

DD is a very essential tie-beam or diagonal strut, wholly preventing any side play, and stiffening and bonding the whole firmly together. It is notched where it crosses the uprights, and nailed to them. The doorway is three feet wide, that between the study and workshop being two feet six inches. The outer one was made wider to allow of the easy admission of our work-bench, as well as the exit of various articles. It is rather awkward, after finishing some piece of work of more than ordinary dimensions, to find that you can neither get it out at the door nor at the window ; but we have known such things occur among other accidents of the workshop. A, shows one part finished by being covered by boards. There are several modes of doing this which must be considered in planning the timbers. The framing shown was designed for horizontal boarding, as here illustrated; but if the boards were to be vertical, it would be necessary to introduce horizontal timbers—one below the top wall-plate, one just above the lower plate, and one running across halfway between them. We illustrate here the best method of boarding such outbuilding at A. The boards are put on so as to lie quite level and horizontal. In this they are generally tongued and grooved, *i.e.*, a groove is planed in the middle of the edge, into which is fitted a strip of thin iron or wood, and the other being similarly grooved, is forced up against it so that the tongue enters this also, and although the boards may shrink and slightly separate, no open space occurs between them. K shows a neat and simple mode of placing upright boards, which are simply nailed on side by side, and then a narrow strip or fillet, bevelled off or moulded, is nailed on where they join. But in this work the precaution should always be taken of not nailing these fillets to both boards, because if this is done and they shrink, the fillets will of necessity split. The best way is to place the boards one-eighth of an inch apart, and to fasten the fillets by driving long thin nails into them down the middle, which, falling between the boards, and passing into the cross timbers behind, leaves each board perfectly free to shrink. At M is shown the method of weather-boarding. The boards here are feather-edged, that is, they are thick on one edge and thin on the other, and they are made to overlap as shown, and nailed one after the other, beginning at the lowest, to the timbers behind, which are, of course, upright, as in the drawing of the house.

Well-seasoned weather-boarding makes a sufficiently neat outside for barns, stables, and other outhouses, and in places where fir is grown it is very much used; it is also made of oak, which is more durable, but more expensive. Its chief fault is that it has a tendency to curl, so that the upper surface of the boards becomes hollow and the lower convex. This is not, however, a serious defect, although it somewhat interferes with the regularity of the boarding. We nailed our boards on to meet at the edges, but attached them to the posts CC, which stood back the thickness of a board behind the level of the corner posts and doorposts. To these we nailed two-inch fillets for the ends of the boards to rest against, and we nailed them to these as well as to the other uprights, but with much slighter nails. The framing of the other sides was similar to that here delineated, except that the ends were gables, and that the framing had to be carried up above the wall-plate. We originally intended to thatch the roof, as affording on the whole the prettiest finish, but as at that time a stable had been re-roofed and slates substituted for baked tiles, we laid hands on these, and found no great difficulty in laying them in an efficient manner. We thus were enabled to dispense with the services of a professional thatcher, and to complete the house entirely without extraneous assistance. We bought a few new and bright tiles, which we laid round the eaves and on all the edges, and also laid them in a double row along the centre of each side. They gave a nice finish to the whole, and made the old grey tiles appear as if they had been specially chosen to complete the design.

Had we lived a few years later, in these days of tarred felt, we might certainly have built our house for less money, and we could have nailed a few broad rough boards as rafters, and covered them with this useful and cheap material. Even the walls might have been so made with a similar lining within, and they would have made a warm and snug building. The smell at first might have been somewhat disagreeable, but we should not have cared much about such a trifle.

There is some skill required, nevertheless, in order to use felt to advantage and to make a neat job with it. In winter it is very stiff, and will crack if forcibly bent. In summer it is perfectly pliable and easy to use, but the tar is apt to come off and mess one's hands a good deal. The surface, however, is usually dusted with fine sand to prevent the surfaces clinging together when it is rolled up for sale, and this renders it less sticky also to the fingers. The neatest way to use it is to cut it into lengths of not more than six feet, and to nail it to a level surface of boards in panels, running a fillet afterwards where the edges meet, and thus dividing it into panels. If the fillets are painted of any light and bright colour, the general effect will be exceedingly pretty; but every part must be made as true as line and square can make it. The boards upon which it is laid must be level, but otherwise it matters not what their shape may be. Outside slabs of fir, or any odds and ends having one flat side, will answer the purpose; but unless, as a whole, they present a level surface, every edge which stands up will show a ridge, and mar the general effect. The boards, however, need not be put close together. They can be nine inches or a foot apart, but should not be much more, or the felt will be apt to bag and appear loose between them. If a building thus constructed is to be used simply as a workshop, the timbers showing in the inside need not be covered, and, indeed, they are exceedingly handy. If, however, it is intended to use it as a study, or for any similar purpose, it should be lined inside with flush boarding, and painted, or, if preferred, it can be papered; but in order to make a good job of it, it will be necessary first to tack cheap calico over the boards, straining it tightly. If this is not done, and the boards shrink, the paper will crack in many places. Having treated a boarded partition in this way with perfect success, we speak from experience. We did not, indeed, even line our study with boards, but we strained canvas over the beams, and thus got a surface sufficiently even to receive paper, and when finished it looked exceedingly neat. We carried the canvas up into the roof also—not to the angle, but to collar-beams about eighteen inches below. We thus contrived an efficient ceiling, which we covered with white paper; all round the angles and up the corners we nailed strips of beading or moulding, so that, when all was finished, no one would have known that the room was merely of wood and canvas. The floor was boarded, but that of the workshop was made of clay, laid and rammed down as hard and level as possible.

We must, however, now recur to some of the timber work. Fig. 15 represents the end of the workshop with the smaller window, showing the timber also of

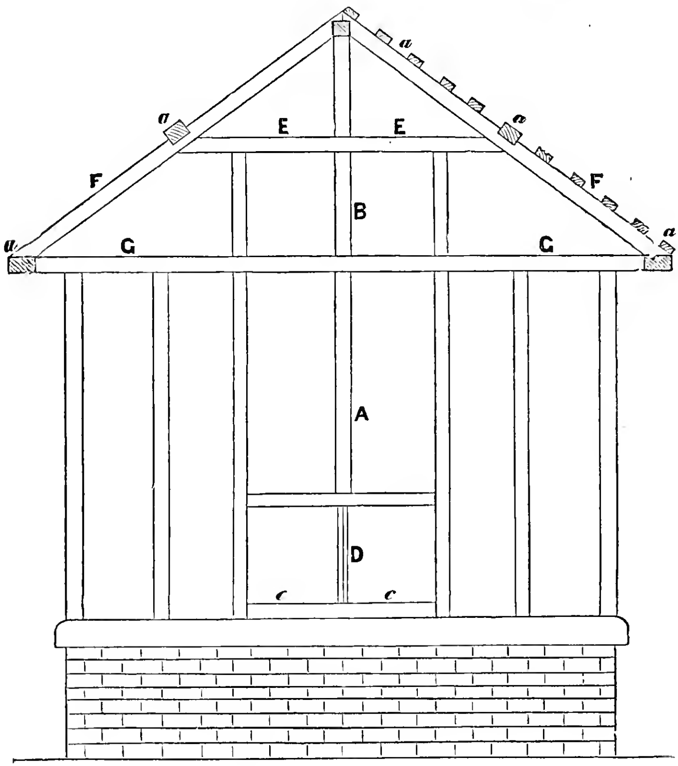

Fig. 15.—Timber Framing.

the gable end of the roof, and the cross-timber ends or purlines, *aaa*, running across from one gable to the other. EE is called a collar-beam, its use being to tie the sloping sides of the roof, FF, together, and prevent them from spreading sideways. GG is a tie-beam for the same purpose; but the last is only put at the two outside *trusses*, as the triangular framework is called, whereas the collar-beams are added to several of the intermediate rafters in order to tie them together, and also to receive the ceiling laths when the ceiling is laid at this height. It is, however, generally at the level of the lower or main tie-beam, GG.

In large roofs, perpendicular rafters are laid over the purlines to carry the laths upon which the slates or tiles have to be laid, and there are several of the main trusses intermediate between those of the gables. In light roofs, however, these are not needed, and the usual way is to nail the rafters direct to the wall-plate and ridge-piece, and to notch in or merely nail on the collar-beams, EE, from rafter to rafter, to carry the ceiling laths, or to assist in stiffening the roof timbers. We notched the purlines just so far into the rafters that they should act as stiffeners, and also as laths. They were perhaps scarcely matters of necessity at all, and it would have saved us some trouble if we had put them inside the rafters instead of outside, where it was necessary to notch them on to bring them level with the slating laths.

Owing to the way in which we had built the house, furnishing the walls with a horizontal wall-plate all round, but projecting at the gables to form level eaves, the rafters did not rest on the actual wall-plates, but on another beam notched down upon the projecting plates, as seen in this drawing, where the shaded part shows its ends.

The construction of roofs of large span is calculated to call forth the highest professional skill of the architect and builder, and is a subject of peculiar interest. The main object aimed at is, to convert the outward thrust upon the walls into direct downward pressure, and to neutralise all tendency of any particular part to bend or sag, by straining pieces, ties, and struts. In fig. 16 we give a few sketches to illustrate this in simple outline.

ABC may stand for a pair of rafters, resting at B and C upon the wall-plates of the two walls, BH and CG. Any pressure on A, or on the lines AB and AC, will tend to make BC spread open, *a* becoming practically a joint, and *ab*, *ac*, the legs of a pair of compasses; and if the points B and C are rigidly fastened to the top of the walls, these latter will at once be thrust apart, and the structure will fall. To prevent the legs thus spreading, we may tie them by a cross piece at the line BC, which is thence called a tie-beam. This, moreover, may be replaced by an iron rod, as it is a true tie, and a rod of this metal will bear an enormous strain without stretching or breaking, if thus applied in the direction of its length.

This tie-rod or tie-beam will thus effectually hold together the lower ends of the rafters, and any weight now applied will merely press downwards upon the walls. If the rafters are very long in proportion to their size, they will be inclined to bend inwards at the middle of their length, F. To guard against this we require a strut, FD, at right

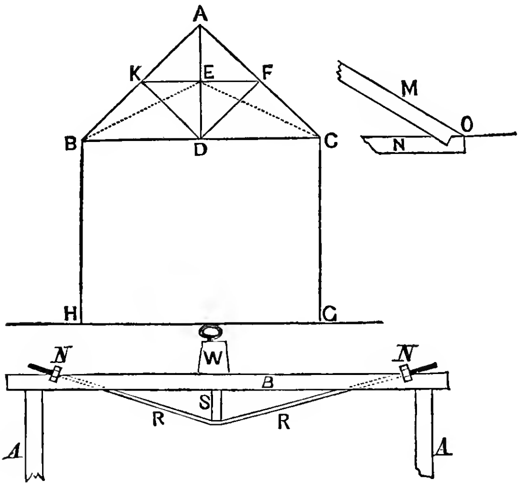

Fig. 16.—Roof Construction.

angles to AC, and here a tie-rod is of no use. We therefore need an abutment for such strut somewhere at its lower end about the point D. Now if BC is a rod of iron, and we rest the end of such strut upon it, it will tend, of course, to make it bend or sag downwards, and a rod, AD, becomes requisite, which will prevent this bending from taking place.

I have supposed iron rods to be used as yet, but with timber a similar arrangement becomes necessary. BC in this case will be a beam called, as before stated, a tie-beam, and AD an upright, called a king-post; FD will be a timber strut. The lower the pitch of the roof the greater will be its outward thrust. If the ridge were at E, for instance, instead of A, the strain would be much greater. Thatched roofs are of very high pitch. Slate roofs much flatter, and a roof intended for tiles will be intermediate between them. When a tie-beam is inconvenient or unsightly, as in an open timber roof where no ceiling is required, it is replaced by a beam higher up, KF, called a collar-beam. This is dovetailed at the ends into the rafters to give it a stronger hold. It is not so effective, however, as a tie-beam, and, when used, the timbers are differently arranged; but each timber and iron rod of the complicated roofs now to be seen in railway stations and elsewhere is essential to the stability of the structure. Even timbers which form arches, or which, by their curved outlines, lend beauty to the design, will, on examination, be found to act as tie-beams, struts or braces.

At MNO of this figure is given the usual method of notching a sloping beam or rafter into a tie-beam to enable it to receive the strain brought upon it, which is an outward thrust tending to make it slip along the beam. The abutment at O effectually prevents such slip; and in heavy work the joint would be either strapped over with an iron hoop or bolted through—generally the former, which does not weaken the timber, as a bolt-hole does.

In our study as youthful engineers, under our tutor's guidance, we made many experiments upon beams and trusses, which also gave us some exercise in practical mechanical work, as we made models of mahogany, carefully finished, with miniature straps and bolts, and rods of iron and steel. In the lower part of this figure is a sketch of a very simple but efficient mode of stiffening a beam or plank which is frequently used in roofs. Let BB represent the beam which is to support a pressure from above on its centre, where the weight W is placed. The tendency of this will be to bend the beam downwards and to draw its extremities from off the upright posts or walls, AA. This may be wholly prevented by placing under its centre a strut or block, S, and adding a straining bar of iron screwed at both ends, so that it can be tightened by nuts, NN, a bearing for these nuts being cut in the beam, so that they shall lie truly at right angles to the bar and bed well and fairly upon the wood. All downward pressure at W tending to bend the beam is converted into strain upon the iron rod tending to stretch it lengthwise

—a strain which a very small rod will bear without yielding. An engineer's business is to calculate these questions of strain and pressure, and to determine what sized rods and struts and beams are needed, so as to render the structure as secure as possible without adding unnecessarily to the weight. This is specially necessary in designing roofs of large span.

A ramble over any old house will serve to show the advance that has been made of late years in the art of building. Those huge oak beams which were then considered necessary, and which in turn needed walls of undue thickness to support them, are no longer used. We set our joists on edge, and saw up the large beams into half a dozen such joists, bracing them where necessary by intermediate struts to prevent side flexure, and we calculate the probable thrusts and other strains to a nicety, in order to economise the material, and consequently the expense of the building. No doubt this economy is sometimes carried too far. The reproach of many a modern town-house is, that its walls are so thin as to be absolutely unsafe to the inhabitants, and not seldom do we read of newly-built houses collapsing before being finished. This, however, is simply the result of false economy, and not of the want of skill in architects and engineers. Many of the houses alluded to are merely raised by speculative builders, who work by plans of their own, and whose sole object is to build houses cheaply for their own profit. In a well-constructed building, every part bonds and supports the other, and the roof exercises no outward pressure tending to thrust asunder the walls which support it, but is simply a solid structure, bonded together at all points, which acts only as a superincumbent weight, exerting a force directly downwards, which the walls, if themselves perpendicular, are exactly calculated to bear. The burden is, in fact, carried by mother earth herself, patiently enough, unless she chooses to set her back up once in a way by an earthquake.

Fig. 17 is a drawing of the timbers of the roof as they would appear when seen from above, but before the battens which are to hold the tiles are put on. These would, of course, run parallel with BBB, which is the ridge-plate at the highest part of the roof; AC is the ridge of the short bit of the roof which comes over the projecting part of the study, but ends at the ridge of the main roof; DD represent the wall-plates, or rather in this case the beam which overhangs the building, and receives the lower end of the rafters.

AE and AF are diagonal timbers where the roofs meet, and to which the rafters both of the short roof and of the long are nailed, forming, when the tiles are on, a gutter at AE and AF, requiring to be leaded under the tiles to carry off the water. As C is the peak of a gable, the end of the projecting part of the building is what is called a pine end—*i.e.*, triangular above the

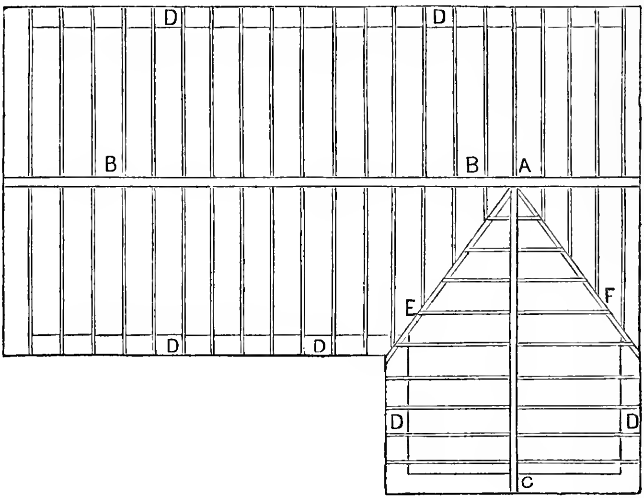

Fig. 17.—Roof Details.

wall-plate. A hip roof, on the other hand, slopes back from the wall-plate to the ridge, leaving the wall, therefore, quadrangular. The rafters in the drawing appear thin because they are set on edge, as is also the ridge-plate against which they abut, and to which they are nailed.

This roof cost us a good deal of trouble, being a severe test of our capabilities as carpenters, but on the whole we succeeded better than we might have expected. We made use of a dodge in fitting which we had seen used by carpenters—viz., a strip of thin board the length of a rafter, and another the length of the inclined timbers EF, which we could cut to the exact angle required at each end, and when we had once fitted this accurately to the wall-plates and ridge-piece, we could mark every rafter by it and saw them off, instead of having to try each one in its place again and again until it should prove to be correct. It is, of course, much easier to fit a thin strip of board than a rafter two inches thick, which, if long, is a heavy affair to manage on the try-try-again principle.

The windows of our workshop were very simple affairs. We merely nailed on the beam, at the top and bottom of the space left for that purpose, a few upright bars of wood rebated to receive the panes of glass. We did not rebate the side pieces, which were also of course two studs of the framing, but merely nailed on some quarter-inch stuff a little narrower than these studs, which had the effect of a rebate. We then cut and puttied in our strips of glass. In this, however, we showed a certain degree of wisdom which may be worth recording for the benefit of other boy-builders. We rightly conjectured that the windows of a workshop would be peculiarly liable to breakage, we, therefore, instead of long strips taking up the whole of each space, placed only small panes, making the upper overlap the lower ones, so that in case of an accident, we could repair damages by inserting a new small pane only. The light was not in this way interfered with, and at the same time the wet was effectually kept out. An advantage in our wooden workshop which we discovered at a later date was the ease with which we could at any time extend our windows in either direction by removing a board or two and replacing it by another strip of glass. We ultimately extended our three-foot light to six feet, and our six-foot one to eight feet, besides adding another in the side wall at the place where we found it necessary to place another vice-bench. We also subsequently converted part of the boarding into a shutter hinged on the top to lift up for the admission of air, and very advantageous we found it in the summer months when we were often glad to throw it open as wide as possible; for though our work was play to us, owing to our fondness for mechanics, we by no means played at work when we were so engaged.

Nothing now remained for us to do of any special difficulty. The laths or battens were nailed on at such a distance apart as to give the tiles a good lap, and the latter, after being fitted with wooden pegs (oak), were duly hung, which did not take us very long. The ridge tiles were then added, and these we bedded in plaster to make all weather-tight and snug.

The framing of the light partition between the study and workshop was a very simple matter, which we carried out after having roofed in the building. The doors were plain ledgers, *i.e.*, upright boards bonded by three across them to carry the hinges and lock. We tongued and groved these boards together and ran a beading down the edges of each.

The wooden floor of the study was laid on joists which rested upon brickwork at each end and in the middle. For this purpose we built up a wall inside the main one on two sides and one parallel to them along the centre, nine inches high above ground. Upon these we laid the joists, taking care that they rested fairly upon the walls, and as soon as we had laid the rows complete, we laid upon them one board and temporarily tacked it down to keep the joists in place, ready to receive the rest. We took as much care as possible to get the boards close together, but did not think it necessary to tongue and groove them. The way in which we got them close together, as we had no flooring cramp, was as follows:—We laid one board close to the wall true and level, and nailed it down securely to all the joists. We then did the same at the opposite wall, thus firmly securing all the joists together, and getting a solid foundation to work upon. Then we laid the next board, but before nailing it we drove into about four of the joists a stout short nail, three inches from the edge of the board lying loosely in its place, and between these nails and the board we drove hard-wood wedges, which, bearing on one side against the fixed nails and in the other against the loose board, forced the latter up close against its predecessor. After nailing this down we drew the nails which we left standing an inch out of the joist, and repeated the operation with the next board.

It is not necessary to describe the few remaining details of our house-building operations, and we shall conclude the chapter by a few words about the arrangement of our workshop after the building was wholly completed.

The large window was honoured with the lathe for which it was specially designed. The small one had the carpenter's bench in front of it, next to which came a stout small bench of three-inch plank with a blacksmith's tail-vice. This was subsequently removed to a new window which we made, as already mentioned, as we found that we required more light when our filing operations were required to be carried out with greater accuracy than in days of early attempts at this apparently easy, but in reality most difficult, work. Above the vice was fixed a drilling apparatus, which could be swung round out of the way when not required, and could be brought exactly over the vice, or over any desired part of the drilling bench. We shall describe this in a subsequent chapter.

The lathe tools had a special rack on both sides of the large window, in which they were ranged neatly according to size; and by this time, in addition to the chisels and gouges, we had a fair stock of variously-shaped tools for hard wood and metal turning. Another rack over the carpenter's bench held the tools peculiar to that work, and planes occupied a couple of shelves above. Files and drills, and hard chisels, pliers, and screw wrenches, had a rack to themselves above the vice-bench.

The next chapter will be devoted to a description of our workshop fittings, as they existed after we had completed them; and although we were not fitted up with any pretensions to stylishness, our workshop was far more complete in its arrangements than many others which we subsequently inspected, and which were more for show than for real work.

Chapter VIII.

OUR WORKSHOP FITTINGS AND APPLIANCES.

IN a previous chapter I have spoken of the renovation of the French lathe-head and the subsequent addition of a cylinder poppit, instead of the simple and inefficient screw in a block of wood which we had been compelled to use previously. The lathe-head with its guide screws was really an exceedingly good one. We found that it was very true, and had simply been laid aside and neglected, more than deteriorated by wear and tear. We therefore saw no necessity for throwing away money on the purchase of a better. The strap pulley, however, was inconvenient when we came to turn metal, because we could not reduce the speed; so we expended a little hoarded cash in the purchase of a grooved fly-wheel and crank shaft, and we then turned a neat mahogany pulley, and grooved it for a gut band. The wooden bed of our lathe we plated with iron, fastened with countersunk screws and draw filed, to make it as level as possible, and to give it a better finish. We procured bars of two inches wide by a quarter thick for this purpose from the blacksmith, which, being rolled by machinery, were quite true from end to end. This made a very good bed, fit for a slide-rest, which we now made up our minds to purchase, although it was a somewhat heavy outlay, costing us, in those days, seven sovereigns. It was, however, a very good one, and twenty years afterwards it was still in almost daily use, and as good as ever.

This was not meant for turning ornamental work, which we rather despised, but only to assist us in making models and other works in metal; and indeed we made a quantity of things, besides models of engines, including a capital set of chucks and various lathe fittings; and long afterwards, when we discovered that ornamental turning needed the highest skill, and was therefore by no means *infra dig.* to a rising engineer, we made a very good slide-rest for that kind of work, and learnt to use it, too, with great efficiency. Knowing the need of steadiness in a lathe, we braced ours at once to the window-sill with a couple of iron rods, so that it was immovable and free from vibration, a very essential point when turning anything at a high speed or using an eccentric chuck.

Our carpenter's bench was made to hold pieces of all shapes and sizes, and we took a great deal of pains to make it. The framing was of the ordinary kind, but planed to give it a better appearance than it frequently wears when made wholly of rough material; but the top of it was of two-inch stuff, and was carefully faced all over, so as to present a perfectly level surface, which we took care to preserve. This is frequently not attended to in home-made benches, in which any stuff, planed or unplaned, is deemed good enough. The consequence is, that it is found impossible to do good work with a plane, because the board, resting on an uneven surface, oscillates under the tool, and a wedge is needed here and there to keep it steady; or a nail or two is ruthlessly driven into the bench to hold it steadily, which nail is sure to be forgotten, and either remains to tear a bit of skin off the workman's hand, or to notch the chisel, plane, or other tool. The way in which planing benches are often knocked about is what boys call "a caution" to behold. It should be as carefully preserved as a dining-room table. There is no necessity to spoil its level surface, for instance, by chucking down upon it any heavy pieces of iron that need a temporary resting-place. No need to bore holes with a centre-bit in work laid upon it without some spare piece underneath to receive the point of the bit when it has passed completely through ; or to chop wood upon it so as to cut its surface gradually into mincemeat. These and similar errors we ourselves had to plead guilty to in our early days of apprenticeship; but having learnt that it was just as easy to preserve bench and tools in good working condition, we duly reformed our manners and customs in this respect.

The top of the bench being level and of thick material, we cut in it special holes and mortises to receive the tenons of certain fittings, to be described presently. The front board, of one-inch stuff, was also carefully planed, and fixed exactly at right angles to the top, and the usual carpenter's vice was fixed at the left-hand corner. This was made with two screws, instead of with one and a guide bar, as is often done. The outer movable board of the vice was of ash, one inch and a half thick, and its upper edge was made to come exactly level with the top of the bench, so that when it was necessary to plane up a narrow strip, it would hold it securely.

At the right-hand end of our bench we fixed another kind of vice, which I think can be rendered clearly without a drawing. It consisted of a block of beech six inches long by three inches each way, with two short tenons below two inches long—one at each end. The block and tenons were all of one piece.

We took, in short, a block five inches deep and three thick, and marking it round on all sides at two inches from the face, which was to be the downward one, and also marking across at two inches from each end, we cut out the piece between the two last markings, so as to leave the tenons at each end. These tenons fitted accurately into two mortises cut in the top of the bench, so that when placed in them the appearance was that of a simple block six inches long by three square standing on the bench, its long sides parallel to the front and back of the bench. It was, however, fixed securely by the tenons. Lengthwise through the block was passed a screw three-quarter inch in diameter. It was our old back poppit screw, but the end was filed off square and flat, instead of being left with a point. In a line with this block and screw were a row of similar mortises at equal distances, into any two of which therefore the block already described would fit at pleasure. To complete the apparatus, there were other blocks, with precisely similar tenons, but only one to each, and these blocks were but three inches, and some two inches, in length, instead of six. To form a vice, therefore, all that was necessary was to put the screw-block into place, and one of the others in a mortise, at about such a distance from it as the article required, and then to fix the latter when placed between them by a few turns of the screw, interposing a bit of hard wood to protect the surface of the work from the end of the screw. Of all our bench fittings, we never found one more serviceable than this, which we used to hold work for mortising, and as a clamp for work glued, and for a multitude of other purposes which need not be enumerated; among others, for holding up pieces which required to be planed on the edge, and which were not so thin as to yield to the end pressure thus applied. We rightly named it "our universal vice."

Another vice or bench appliance of great use in planing pieces too thin to hold in any other way, consisted of a block of wood similar to the last, but sawn about three-fourths of its length through, so as to form a kind of spring-clip; through this a screw was placed crosswise, so that when turned by a short bar, it brought together the two sides of the wood which the saw cut separated. This acted, therefore, as a vice for very thin laths, which were, of necessity, held at the end from which the plane started on its way, *i.e.*, the right hand, so that the force of the plane only tended to stretch the strip, and not to bend it. All thin laths need to be planed in this way. We also had blocks with a deep saw-cut, or rather deep shallow groove made by two saw-cuts, one-quarter inch apart on the upper surface, in which thin slips could be fastened by a wedge, and various similar contrivances for holding boards on edge, cylindrical and other shaped pieces, which often saved us much time. In short, the mortise holes and blocks were as useful as they were cheap.

We also had a couple of round holes to take the stem of our bench hooks or bench holdfasts, of which one was of the old pattern, the other made with a screw to hold down work. We had also a carver's screw, a most useful contrivance. It is an iron bolt with a screw and bow-nut at one end, like those used to secure lathe poppits, and a short conical screw at the other. The latter is screwed into the block of wood to be carved, and the bolt being passed through a hole in the work-bench, is secured by the bow-nut and a large washer underneath. Then we had also for use with the tenon saw a short strip of ash, with a piece at each end projecting an inch, but in opposite directions. One of these rests against the edge of the bench upon which it is laid, while the other prevents the strip of wood from escaping under the action of the saw. Its form was like the letter Z, but the central line much longer in proportion, and at right angles to the two other lines which make up that letter. We had, of course, the usual planing stop in addition to these other contrivances, a very much better form of which is now made wholly of metal, and getting into very general use.

The next workshop fitting which it is necessary to describe is our filing or fitting bench. This was of three-inch plank, fitted to the wall by a pair of bolts going right through two of the joists, and screwed up with a nut and washer on the outside. It was also supported by two legs driven into the ground, and then notched into the bench and fixed with screws. The tail-vice, with chops three inches wide, was fixed to the front of this, the leg being let into a short pile of oak driven into the ground. It was therefore very firm, and stood just so high as to bring the vice chops on a level with the elbow, which is the best height for accurate work with the file. Under the bench was fitted a strong drawer, to contain various odds and ends, such as screw taps, and dies, drills, small bolts and nuts, and the thousand and one etceteras of a smith's shop. We had not, however, at the time, any forge, and although we afterwards had a portable one, we only used it for soldering, brazing, and doing light jobs. We found it cheaper as well as better to get our forgings as well as our castings done for us by those regularly trained to that work. We did, indeed, now and then cast small articles of brass, using blacklead crucibles, with coke as the fuel; but we so often found these articles turn out badly, that, as a rule, we did nothing in the way of founding. Still we could bend and weld light ironwork with the forge, as well as heat rivets, alter the shape of slide-rest tools, make an occasional carrier for the lathe, and so forth. Our forge proved, therefore, very convenient, but was never admitted into our workshop, but used out of doors or in an old shed.

Our drilling apparatus was at first merely the ordinary blacksmith's brace pressed down by a lever overhead, with a weight hung on at the end of it—a clumsy affair, still to be met with at smith's forges in some country places, and certainly effectual, as is proved daily by the work done by its aid. It was, however, very much of an eye-sore, and took up a good deal of room. We therefore replaced it by an upright rod of iron, and a sliding arm with a screw passing through it, to give the necessary pressure to the brace. This upright rod was fixed by being made to pass through the vice-bench and rest upon a collar, which prevented it from falling quite through, but allowed it to swing round. Underneath the bench it had a washer and nut, and a similar washer was let into the top of the bench where the rod passed through it. Near the top it passed through an eye-bolt, which, in its turn, was screwed into one of the upright studs of the workshop; then the rod, which was of round iron one inch in diameter, was very securely fixed in an upright position close to the wall. The arm which projected from it was of flat bar iron half an inch thick, with a boss or enlarged part at each end. This, when fixed, was so placed that the edges were above and below, and the broad or flat parts sideways. The iron in this direction was an inch wide. It was made thus stiff, because it was necessary that it should stand a good deal of strain without bending. Both bosses were bored through—the one to slide up and down the upright bar, the other to receive a screw six inches long, with a hole in the lower end, into which the upper pointed end of the brace fitted when in use. This end was case-hardened, as was also the point of the brace. We have not drawn the latter, as it is a tool well known to boys of a mechanical turn, being found in every blacksmith's shop in the kingdom.

Those were not days of twist drills, nor of the fluted drills, which are equal to them, if not superior, but we had a set of common diamond-pointed ones made to fit the brace, which was not our own handiwork, and we soon learned how to make and temper them ourselves—an accomplishment always of value to the mechanic, old or young. It is here, indeed, that the generality of amateurs lag behind. They require sets of drills, reamers, countersinks, and such-like; and if they need to make a hole for which they have not a drill of precisely the required size, or if they chance to break a tool of this description, they are at a stand-still till they can buy a new one. Not so the workman. He simply puts his broken drill into the fire, and with a few strokes of the hammer remodels it, making it smaller or larger to suit the job in hand. Then he tempers it, and grinds it, and in a few minutes is diligently at work. A chance breakage is, in fact, to a good workman, of no sort of importance, but with him it is not so frequent as with less skilful hands.

When first we tried to make a drill or two, as we had seen the village blacksmith do, we burnt the steel, which forthwith crumbled under the hammer, instead of taking its proper shape, as we expected. We then found that a white heat would not do at all, but that we must not raise the heat beyond what produced a bright red, and that we could shape our work at this temperature without breaking it. Then we heated it to a bright red and quenched it, ground it to a nice bevel, and broke it short off at first trial. It was a great deal too hard and as brittle as glass. Then somehow we learned that it was, as a general rule, necessary to *let down* the temper of drills, taps, reamers, and indeed of most other tools subject to strains or to sudden blows, by first heating and quenching, and then heating them again to a stated temperature known by the colour which the metal takes under the influence of oxidation. As the temperature rises the steel becomes softer, and when at the desired degree it is suddenly quenched again in water or oil. In this way we found that we could make steel so hard that no file would scratch it, and from this let it down as we pleased. Drills for metal, unless for drilling steel, answer when the deep straw colour is attained, or when this is beginning to change towards a blue. The shank of the drill should be then tempered, even if the point is left hard. This may be done by laying the shank on a bar of red-hot iron and watching the colour as it spreads from that point up and down the surface of the drill. Screw taps, again, being subject to torsion, or a strain tending to twist them, need very careful tempering, especially if not very well made, as they then cut with difficulty, and require more power to work them.

We found out such matters as these chiefly from numerous failures, which often teach more than success; but we also learned the use of our eyes and ears, and picked up many a wrinkle while innocently watching the work of various tradesmen, but especially that of the blacksmith, who, in country villages, combines the trades of farrier and shoeing-smith, tinman, brazier, and machinist. In short, to a skilful village smith nothing seems to come amiss in the way of metal work, and some are very skilful in making axes, billhooks, and edge tools, which stand work a great deal better than those ordinarily purchased at tool-shops. Of course, if it comes to a question of appearance, the tool-shops carry the day, for at these you may buy axes beautifully polished for a part of their blades, and the rest got up with a wonderful blue, which renders the whole tool marvellous to behold; and it is a far greater marvel if a tool thus finished proves of any value at all to the buyer.

Of trestles, sawing-horses, and low stools of thick stuff with stout legs, for cutting mortises upon, it seems hardly necessary to speak, yet we have known these conspicuous by their absence in many a workshop of no mean pretensions, in which, if a board required to be sawn off, there was a hunt for something upon which to rest it. The best framed trestle we had was made after the fashion of the Roman capital letter A. I fancy we had seen it somewhere, for I doubt if we invented it ourselves. The board to be sawn (lengthwise) was slipped through above the cross piece in the centre, and the legs of the A were pushed slightly outward, so that the end of the plank rested on the floor behind the workman, while the other end to be sawn projected, and was held up by the legs of the trestle. As the sawing proceeded, the board was slipped further through. This device holds the board in the most convenient position possible, and is as easily made as an ordinary sawing-stool. When the board to be sawn was thin and of any great length, we found it necessary to place an ordinary stool in front of our alpha horse to support the end, which otherwise would be found careering and prancing up and down at every stroke of the saw, as if in mortal agony, while its sides were being split, but not with laughter. Of all work which boys are inclined to be shy of, sawing stands pre-eminent. In the first place, they find it very difficult to drive a straight course; and in the next place, it is uncommonly hard work; and we often see boys splitting a board instead of sawing it, by which, as the crack seldom runs straight, they are sure to waste material. This laziness we never allowed ourselves to be guilty of. We kept a half-rip and a hand-saw in good order, and soon found arms and back grow used to the work, and we made nothing of the labour of sawing a three-inch plank twenty feet long from end to end. In these days, however, one has not very much to do with such heavy work, as it is easy to get at the saw-mills any description of scantling, and the circular saw will rip up such a plank as alluded to in about a minute.

Talking of circular saws reminds me that I have not spoken as yet of this handy and not very costly addition, which we found means to make to the fittings of our workshop. In those days such articles were not so easily obtainable as they have since become, and we bought a saw of six inches diameter and made a stand for it ourselves, turning the spindle also upon which it was fixed. A circular saw is only a round disc of steel with a central hole in it, the teeth being cut round the edge. A spindle with a shoulder is passed through the hole, and a washer placed on the other side, which is forced up against the plate by a nut. Upon the spindle a pulley is fitted for a strap, and the whole is fitted up in other respects like a lathe, the saw being driven by a fly-wheel, crank, and treadle. A flat table, however, takes the place of the lathe-bed, in which is a narrow slit to allow the saw to project through it nearly to its axle; and upon this is laid the work to be sawn. A six-inch saw will cut, therefore, only about two inches, owing to the thickness of the spindle and its collar and nut; but a piece of wood two inches thick we found quite hard enough work for our legs; and, indeed, we seldom used the saw upon more than one-inch stuff, as neither of us, in spite of our ingenuity, had been able to make for ourselves a steam leg to drive the machine. Upon the saw-table there was a stop or guide, a strip of wood an inch thick standing up parallel with the saw, which could be adjusted to any distance from it. This enabled us to cut strips of any width all true and all exactly alike. We had also angular guides for mitres, bevels, and such-like.

The handiness of a circular saw can hardly be overestimated. For any heavy work it is indeed useless when worked by the foot, though capable of any amount of work when steam power is used to drive it. But for light work it is invaluable, and no workshop can be considered complete without one. We had the spindle mounted between two pointed and case-hardened screws under the table, and we could remove this saw and replace it by one for cutting metal, to saw off ferrules from brass tubes and such-like. We also had other spindles fitted like a knife-grinder's machine, with small grindstone and emery-wheels, commonly called emery-bobs, and also with polishers or glazers covered with leather. The machine, therefore, was of somewhat extensive use; and one day, when we had left our door unlocked, the knife-boy made free to enter our sanctum, and try our precious buff-wheel as a cleaner of knives—an operation which was so successful that we took care the experiment should not be repeated. We did, however, make a special knife-cleaner, which remained some years in constant use.

There is a mode of using a circular saw which we imagined to be an invention of our own, but whether or no it was so I cannot now determine. We raised the table by adjustable wedges, so that the saw might project only a very little above it, and we then used it for cutting rebates, such as are made in picture-frames and sashes to hold the glass. We first cut the strips with the table lowered down to its normal level, and then using the parallel guide, we raised the table and made a saw-cut from end to end of the piece, which we met by another at right angles to it. The two cuts of course removed a square slip of the wood, and so formed the required rebate. We used it thus for picture-frames, of which we made several, as for many other purposes.

Long since that time this mode of rebating frames has, I believe, become general, and the circular saw is put to every kind of work which it is capable of executing, as well as to work which no one would have supposed could be done by its means. Revolving cutters, by which clock wheels are cut, taps grooved, and drills fluted, are but circular saws of various sections and of small size, which are, many of them, driven at a terrific rate, and make splendid work in skilled hands. Of these we made, however, no use in connection with the machine alluded to, although we learned to use them with our lathe after we became possessed of a slide-rest.

We may here mention, for the information of mechanical boys, who like to know how all sorts of things are made, even though they themselves may not be trying their skill at mechanical work, that the revolving cutters are used extensively for making the various parts of sewing-machines, some of which are of so peculiar a form that, I daresay, many have wondered how they could be so beautifully made by means of files and ordinary methods of work. In the Government factories, also, where small arms are made, the same tool is in extensive use. In cutting V-grooves in the edges of brass slides for eccentric chucks, cutters of that section are adopted, and the work is not only done very rapidly, but with a correctness scarcely to be attained in any other way, although, before such appliances were known, the skill and perseverance of the filer and fitter proved equal to the task. It is, however, very difficult to file a groove accurately along the edge of a plate, and it will prove a rather hard trial of the mechanic's skill to do it. Cutters can now, however, be had at all good tool-shops, beautifully made, and of almost any section; and any young engineer who possesses a lathe and a slide-rest ought to add a cutter spindle, and learn to use it.

When our stock of better-class chucks was extended, partly by purchase and partly by home manufacture, we had a glass cupboard, or rather a cupboard with shelves and a glass door, in which to keep (and show) them. We found that unless they were put into some such receptacle, the dust of the workshop made them exceedingly dirty, and mixing with the oil, got into the movable parts, and did, in course of time, real damage by grinding such parts, and rendering them loose. Some of our best tools we also, for a similar reason, kept in drawers and boxes, as we had learned that good tools were worth careful preservation, and would not do best work unless they were thus preserved. Our big grindstone for ordinary shopwork had a place in the workshop away from the lathe. It was about two feet in diameter, mounted accurately on its spindle, and fitted with a crank and treadle, besides having a handle that could be put on at pleasure for grinding axes or heavy work. There was a water trough below, which was lowered when not in use, so as not to keep the stone wet in one part, and also a cap or hood, to prevent water from being thrown about the workshop, or annoying the workman by splashing his face and clothes. It is now the fashion to use, in place of grindstones, revolving emery wheels, going at perhaps 1500 turns a minute, and having a stream of water constantly running over them to keep the tool from losing its temper. Even with this precaution it is difficult to prevent heating the steel, which, if the stone is run dry, may be made red-hot in a few seconds. These emery wheels are also used to take off the hard scale or crust from castings, which is so detrimental to tools, and which has to be removed by the tedious processes of pickling and chopping, unless these emery wheels are brought into use for the purpose. They were, however, quite unknown when we built our shop, and were, therefore, not among its fittings, and only quite recently have they become common.

Such was our workshop as designed and made by us with no professional assistance whatever. To this day I look back upon it with pride, if not with affection. It is one of those possessions that make an impression on the mind of a lad not easily effaced, as it was essentially an integral part of the home of our boyhood and early manhood. Even its association with the study did not take in the least from the charm which it possessed; in fact, that study was entirely our own device and our own suggestion. I have, indeed, heard some boys speak disparagingly of their school-days and school-work, with its strict discipline and restraint, but it is a feeling of which we personally never partook, even in our youngest days. As to discipline, we had always been trained to yield implicit obedience to those who had charge of us, whether at home or at school, and it was cheerfully rendered. Moreover, as we advanced beyond those earlier studies of childhood, which are, of course, always more or less tedious and disagreeable, we liked learning for its own sake. We were both naturally of inquiring disposition, and longed to escape from the trammels of boyish ignorance, which we rightly believed kept us back from a good deal of intellectual enjoyment. We won prizes, but we did not in reality work for them; they fell to our lot as a matter of course, and were appreciated not as something to show, but as mines of valuable information; for they were always well chosen, and of an interesting character. When, however, we rose higher in the school, we *did* work for the prizes, because the elder boys were, by a wise arrangement, allowed to select prizes of a certain fixed value according to their respective tastes, and even to add from their own pockets if the prize selected was beyond the money assigned to them. I need hardly say that our choice was invariably a book connected with mechanical arts.

In speaking of what we did, and how we worked at what was first a mere boyish hobby, but ultimately became the life's business of one of us, and for a time of both, I cannot help feeling that I am to some extent egotistical. Everything recorded of necessity bears this stamp. It is nothing but *ego* and *ille alter ego*. I shall conclude this chapter, therefore, with a record of a very dear father, who, if he had a fault, was only too indulgent. He too was naturally mechanical, but in another direction. With him the sea and the Navy, to which he belonged, and which he certainly adorned, was everything. As boy and man he was for ever making models of ships; and well do I remember how patiently he worked, and with what simple appliances he executed all with a precision and neatness hardly to be excelled. I have several of those models now, and though I have seen many of similar character, I never saw any better made. The hulls were not merely carved out of a solid block, but built up from the keel rib by rib and plank by plank, all riveted with brass wire nails or fastened with copper studs and bolts. It is still a matter of wonder to me how he curved those small planks so gracefully round the bows and under the quarters, and how he prevented the board from splitting. I believe, however, that the holes were all drilled with one of the bow-drills used by watchmakers. Then, again, masts and spars were rounded entirely by hand, and were finished to perfection; and there was the miniature wheel with its facings of brass, the binnacle with its compass, the hatchways and gratings and hammock nettings, each and all as complete as skill could make them, and a sailor's critical eye could plan them. Even the sails, I believe, were my father's own handiwork, beautifully stitched and finished as they were; and the little blocks with running sheaves in each, double or single, as in a real man-of-war, were cut and carved with the same untiring patience. Alas! those ships are things of the past. Wooden walls are fading away before the iron-built ugly monitors, and perhaps the old sailor, of which my father was a fine type, is also passing away.

Chapter IX.

ONE OR TWO ENGINES.

OUR house completed and shop fairly furnished with the necessary tools, our ambition centred on a steam-engine, as, I believe, is almost always the case, sooner or later, with lads of a mechanical turn. This is not unnatural, for whatever other machine or model of machine may occupy the attention from time to time, the steam-engine is at present the grand prime mover, without which they would be practically useless. If we could have managed to bore a larger cylinder, and to make or procure a suitable boiler, we should have tried our hands upon one of a size to do useful work—to turn our lathe, for instance, when we were engaged in any heavier work than usual. As it was, however, we were restricted in various ways. Our pockets were not over-heavy, our mechanical appliances limited, and we could not manage to bore out a cylinder of the size that would be needed for the above purpose.

We eventually decided on a cylinder three inches long, with a bore of $1\frac{1}{4}$ inches, which was as much as our lathe and slide-rest were likely to do in a satisfactory manner.

We were saved, at all events, one great trouble, namely, the construction of patterns for casting. We happened to have amongst our acquaintances a member of a noted firm of ironworkers, whose foundry was about ten miles off, and from him we obtained for a nominal sum all the castings of this engine complete. These consisted of cylinder and its covers, valve box and cover, piston and eccentric, guide bars and pillars, all of iron, eccentric straps of gun-metal, bearings for the crank shaft of the same metal, iron fly-wheel and bed-plate. The forgings we found it easy to obtain in our own village; but these were very few—merely the forked connecting-rod, and one or two odds and ends. The boiler we left as a matter for consideration after the engine should be completed.

Before setting to work upon the engine, however, we endeavoured to gain such a complete insight into the theory of steam as a motive power as should give us greater interest in our undertaking, and serve to lay a sound foundation for future studies. It is here, I think, that boys usually fail. They exercise their ingenuity upon the fabrication of machines without any real knowledge of the why and wherefore, and consequently, if ever finished, the models serve merely as toys, which teach them nothing, and are soon cast aside, as the interest in them ceases.

I don't mean to say that we then moralised more than other lads, but as our profession was to be that of engineers, we took all pains to learn theory and practice at the same time, and thus gained a good deal of knowledge in an exceedingly pleasant manner.

To begin with the water in the boiler, out of which, by the aid of heat, we have to procure the steam required for our purpose. Water is not a simple element, as was formerly supposed—that is, it may be disintegrated into two separate substances, which, strangely enough (for we should not have conjectured this), are gases, which are themselves invisible to the sight, and have nothing about them suggestive of moisture. The one gas is oxygen, the other hydrogen, which obtained its name from the fact of its being an important constituent of water, as our young Greek scholars will at once understand; while oxygen was named from being the supposed originator of acidity—like some boys, it is a "pickle." These two gases, when mixed together in certain proportions, are very ticklish customers to deal with. Looking exceedingly innocent and harmless—when in a glass vessel, the latter appears to be empty—they are highly explosive, and only await a chance spark to make them go off with a bang. Hydrogen gas alone will not do this, but will burn with a faint blue flame, which, however, is intensely hot, and will, if a stream of oxygen is driven through it, melt the most refractory substances in nature.

A mixture of hydrogen and oxygen when exploded produces water; the two gases, if in suitable proportions—viz., 8 of oxygen to 1 of hydrogen—combining wholly, and leaving no residue. If these proportions are exceeded in either, the excess will simply remain unaltered. In a mere experiment on a small scale, with the gases in tubes or other small vessels, the result in water will only appear like dew upon their surfaces, so that boys who perform the experiment need not expect, as we did, to see a tube half-full of water as the result, because the gases thus combined take up infinitely less space than they did before.

In the vast laboratory of nature, chemical actions go on upon a scale of which the student has no conception, but I do not know that the explosion and combination of these gases occurs naturally; the Creator having furnished our Globe at once with this compound substance, which is essential to our life and happiness.

Now this compound is itself, under certain conditions, explosive—a fact upon which experiments have yet to be made, and which deserves more attention than it has yet met with. You may not unfrequently have noticed that a tea-kettle boiling over on a hot kitchen stove will keep on jumping as the drops run down its sides, get under it, and come in contact with the heated metal below. If the iron is sufficiently hot, the water will, on reaching it, separate immediately into globules, which do not at once become vaporised, but hop and roll about, till, with a slight explosion, they become instantaneously dissipated. The following quotation from Lardner's "Natural Philosophy" will suffice to give all the information necessary upon this point. The paragraph is entitled "Spheroidal state of liquids":—

If a drop of water or certain other liquids be let fall from a funnel terminating in a small and fine tube upon a surface of metal rendered red hot, the following remarkable phenomena will be manifested:—

1. The liquid will not wet the surface, but will appear to avoid touching it, and will assume a globular form like that which water affects when it is diffused on a greasy surface, or like globules of mercury upon glass.

2. Instead of entering into violent ebullition, as might be expected, the temperature of the liquid will be very little affected, and the drop of water will either remain at rest, or be affected with gyratory motion.

3. When the surface on which it rests is cooled down

to the temperature of 400° or 500°, the liquid will begin to diffuse itself on the surface, and will be suddenly scattered with violence in all directions. These experiments can be most conveniently made with a shallow capsule of metal shaped like a watch-glass, which can be kept at a white heat by a powerful lamp. The liquid can be let drop upon it by a fine pointed syringe or funnel.

I have recorded this peculiarity of water, because it is one upon which boys as well as men can make valuable experiments, and because it has been thought that some of those terrible steam-boiler explosions, of which we too frequently hear, are caused by the explosion of water within, which in contact with a highly-heated surface becomes spheroidal as above stated. Some have also broached the idea that the water in these cases not only assumes the conditions alluded to, but is even decomposed into its constituent elements of oxygen and hydrogen, which, if it is the case, would amply account for the wide-spread destruction which occurs.

There is no doubt at all of this, that no safety-value yet devised will counteract the effects of a sudden and instantaneous increase of pressure within a steam-boiler. It literally has not time to act until the mischief is done, the explosive force acting first upon the parts immediately adjacent to the scene of action.

This is often proved by the bursting of an ordinary shot-gun, which will occur from a cause apparently quite insufficient to produce such a disaster. A small piece of dirt, for instance, stopping the muzzle never so loosely, will not be driven out, as would be supposed, when the gun is fired, but will instead cause it to burst. A piece of thin paper pasted over the muzzle will do the same, slight as the obstruction may appear to be, although it would naturally be supposed that such a substance would instantly tear and allow the charge to pass through it.

Take a glass tube and blow a pea through it, which all boys know is a remarkably easy thing to do. Put a cork in the end or close it with a finger, and try to hit your finger with the pea; you will see it stick fast to the side of the tube, you can't blow it forward at all, and all you do in the attempt is to condense the air in the tube, and cause it to press the pea firmly against the side. Again, take a glass tube, and cutting out a disc of cardboard with a central hole to fit the tube, attach it to the end. Upon this lay another disc of the same size, say two inches diameter, now blow off the top one, holding the tube upright. Of course it is easy to do so! Is it? You will get black in the face before you can do it, although there is apparently nothing to prevent it.

This last experiment has hardly, perhaps, as yet received a satisfactory explanation, but all tends to show that causes may exist for explosion of steam-boilers against which it is difficult wholly to provide. Safety-valves, however well designed, have often failed in their action, and before the suddenly-increased pressure has had time to lift the valve, the boiler has given way. It is different with a pressure gradually and steadily increased. In this case the force spreads evenly, and the valve provided for the purpose feels the effect, and has time to yield to it, thus saving the catastrophe that must otherwise occur. If you stand at a railway station, you will not see the steam escape in a series of puffs from the safety-valve or the top of the boiler, but pouring forth in a steady stream as soon as it has attained power to lift the valve from its seat. I may remark, too, that if you could look into the boiler you would see no steam at all, but a perfectly clear space above the water, because steam is not visible until, on escaping into the atmosphere, it becomes cooled and condensed into minute drops of water. If you look at the glass guage which shows the exact height of the water in the boiler, and of which the upper part is full of steam, you will not see the latter, which is nevertheless there, and ready to do you faithful service at any moment.

Water is commonly said to boil at 212° of Fahrenheit's thermometer, and this may be said to signify that, at ordinary atmospheric pressure, it will at that temperature be converted into steam; and the more you stir up the fire, the more rapidly will the process take place, until the water becomes, as we say, wholly boiled away. Like many other common sayings, it is not exactly true that water boils at this temperature, because it depends on various concomitant circumstances. The water, for instance, must be pure and the barometer at a certain height, *i.e.*, the weight of the air must be at a specified number of pounds to the inch of surface, which the barometer will show as equal to 29·921 inches of mercury. If the pressure of air is less, as on the top of a mountain, the boiling-point will be at a lower temperature. At Baréges, in the Pyrenees, 4164 feet above the level of the sea, the boiling-point is 204·8, the barometer standing normally at 25·51.

Now in a steam-boiler the pressure is of course very great indeed, and rises with every degree of heat applied, and the water in this case is not converted into steam at 212°. In proportion to the increase of pressure, the increase of the temperature at which the water boils takes place. The pressure of steam on the inch at what is called one atmosphere is 15 lbs. If this is raised to 30 lbs., the temperature of the water at boiling-point will be 250° instead of 212.° Before we can state, therefore, the temperature of the water when it begins to pass into a state of vapour, we must know what the pressure is upon each square inch of its surface.

Before we can understand the steam-engine thoroughly, we must also know how much steam a certain quantity of water will produce, and this is remembered easily enough, for a cubic inch of water will expand into a cubic foot of steam, or so nearly that this will answer as the starting-point for any calculations that it may be necessary to make upon the matter. Let us go a step further. Suppose we place a cubic foot of water into a close vessel and evaporate it into steam, it is evident that it will exert an enormous pressure on all sides, tending to burst the vessel, or boiler as it is called in reference to the steam-engine.

It is this pressure which is made use of in the steam-engine, and the limit to which it can be raised is probably that of the strength of the boiler. In the present day these boilers are made with great care and skill. They are of iron plates riveted together, generally in the form of a cylinder, as it is the simplest and also the best to withstand internal (or external) pressure; and in order to add to the heating surface, and thus raise the necessary steam as quickly as possible, tubes pass through it, either a number of small diameter, as in railway and marine-engine boilers, or fewer, as in the Cornish engines, in which there is either one large tube going through from one end to the other, or this is turned and brought back again, forming a pair of tubes, in which the flame from the fire-grate and the heated gases constantly circulate. These tubes do not weaken the boiler, as might very naturally be supposed, but act as stays or bonds. Those of a locomotive, which may be as many as 200, of about two inches diameter, and which run from the fire-box at one end into the smoke-box at the other, are fixed into the two external plates by conical rings of steel, driven into them at the ends when in place, thus forcing them outwards against the holes through which they pass. These end plates are of much thicker iron than the rest of the boiler, because the number of holes made in them weakens them, in addition to which it would hardly be possible to fix the tubes in thinner plates, as there would not be sufficient substance to resist the pressure of the conical ferrules. Fixed by these, any of the tubes can at any time be easily removed and new ones supplied in case of wear or accidental breakage; and in engine-works you may often see whole piles of these tubes which have been removed, in order to get at the inside of the main boiler, and which will be replaced and secured as before in a very short space of time.

Large boilers are, in addition to careful riveting of the plates, strengthened by stays and struts inside of cast or wrought iron, to assist in resisting the enormous strain to which they are subject when in use. This strain, at 40 lbs. to the inch, will amount to no less than 2½ tons to the foot, tending to tear the plates asunder. This pressure is, however, as a rule, considerably exceeded, and with perfect safety if the boiler is well made; yet the plates of which it is composed are less than half an inch in thickness.

Perhaps some of my readers may wonder how it is that they do not see any of the rivets when looking at a railway engine, except those at the two ends. The reason of this is, that the body of a boiler is always covered with a lagging, as it is called, of wood, with a layer of woollen felt underneath, to prevent the heat from escaping by radiation, as it would otherwise do. This is laid on in thin strips, and hooped over like the staves of a cask, and it is then painted a bright green or other colour, and varnished. The actual boiler plates are thus wholly concealed, and the engine wears a bright and handsome appearance, which is enhanced by the bright gun-metal fittings and polished rods of iron and steel.

The main point to be aimed at in the construction of boilers is, to give as large a heating surface as possible, so as to produce steam with rapidity, and with a small consumption of fuel. Hence, the value of tubes, through or round which the fire and hot gases are made to circulate, each of which represents therefore so many square inches or square feet of heating surface. In spite of all care in lagging both boiler and cylinders, it is found impossible to utilise satisfactorily all the heat given off by the burning fuel. There is always some degree of waste, and although, as a rule, the cylinders are brought as near the boiler as possible, the pressure existing in the boiler is never wholly imparted to them. Some engines, too, consume more fuel in proportion to the water converted into steam than others made from the same patterns, and in all respects exactly like them. There is, in point of fact, even in the best-made engines, a great loss of power from excessive friction and other causes, in spite of constant so-called improvements and additions. But of all engines to waste power, models are the worst. They are, as a rule, the most useless and unsatisfactory machines in existence. There is, first, the difficulty of heating the boiler efficiently, especially where gas cannot be had for the purpose. The fire-grates, if such there be, are too small for coal, coke, or charcoal, and the draught insufficient. If spirits are used, they boil over, joints are unsoldered, paint burnt off, a great mess made, and very probably substantial injury to the table is the result. With regard to solder, indeed, I readily admit it should never be used, but in *small* models it almost becomes a matter of necessity, and in bought ones cheaply made, it is quite certain to have a place. I have seen a pretty locomotive take its first trip half the length of a table, and quietly fall to pieces then and there, while the spirit, having boiled over and ignited, meandered in luminous streams all over the table. It is always, therefore, the best plan to work upon as large a scale as the state of the funds will allow; and our engine with its three-inch cylinder never gave us much trouble in the above particulars, because all the parts were large enough to be put together with screws and bolts and rivets, and the boiler had a sufficient firé-grate to allow a good layer of charcoal to burn within it. The draught, too, so necessary to keep the fuel in a state of incandescence, was amply maintained when the engine was at work by sending the waste steam up the chimney in the orthodox way. As to the additional labour entailed by a model of large size, it was not to be compared with the advantages otherwise gained. Moreover, we gained far better practice in filing and fitting than we should have done with a very small engine.

The first thing we did was to make a very careful full-sized drawing of every part—a true working drawing, from which we could take off distances and sizes, with the certainty that we should be right if we followed them exactly in the construction of the engine. Without such drawing our work would have been of that haphazard kind which never did answer and never will. We had, moreover, here an advantage over makers of large engines, in that we could draw every detail of the full size, thus escaping chance mistakes, which often occur in reading from a scale. In machine-works, drawings are made of a certain number of inches to the foot—three inches, for instance, in a drawing signifying three feet, or any other quantity determined. It is easy to understand how, in making drawings, or in reading them off for the actual construction, mistakes are liable to occur, which may, perhaps, not be discovered until the various parts are ready to be put together. With our own drawing, three inches stood for three inches, and we were not obliged to refer to any scale of parts in the prosecution of our work.

Centre lines were not forgotten as starting-points from which to measure right and left, so that if a slight error was made, it would not be multiplied by constant repetition. No one accustomed to work as boys usually do, in a happy-go-lucky style, can have any idea of the confidence imparted to a workman who feels that the drawings laid before him are thoroughly trustworthy; and to work with confidence is to work in a masterly manner. In making, for instance, the connecting rod, or in filing up a bearing, or turning the axle of the fly-wheel, we had not to set each up in its place to try whether it was exactly the size required. All we had to do was to refer it to the drawing, and if, on careful measurement with the compasses or callipers, it was exactly in accordance with the drawing, we laid it down with perfect confidence, and proceeded to make some other part. The result was, that when all were finished, they dropped into their respective places on the bed-plate, and every part proved satisfactory.

The first consideration is invariably the accurate boring of the cylinder. This cannot be *satisfactorily* done without a slide-rest, although, no doubt, it is *possible* to do it. There are, moreover, two methods of accomplishing this work. The first is to chuck the cylinder, and fix a boring tool or inside tool in the slide-rest; the second is to attach the cylinder itself to the rest, and to use a boring bar, *i.e.*, a bar of iron mounted between the lathe-centres with a boring tool fixed in a slot which passes through it. This tool revolves, while the cylinder is made to travel slowly onwards. This is the way in which large cylinders are bored, and a great deal of similar hollow work; but to accomplish it the rest must be wholly self-acting, traversing along the bed by means of a screw or rack, to which motion is given by a set of wheels and pinions in connection with the mandrel. For smaller work this plan is not so often used, and as our lathe was of the simpler kind, we had to chuck the cylinder and use a fixed tool. The proper chuck for such work is a face-plate of iron turned perfectly true upon the surface, and furnished with what are called dogs—*i.e.*, clamps to hold any work securely down upon the face of the chuck. The latter may be of the universal kind. There may be, first of all, the face-plate, and then a pair of sliding jaws like those of a vice, but of curved outline, which can be made to approach each other, either by a single screw with a right thread on one half and a left-hand thread on the other, or by a pair of independent screws. The first method forms a self-centring chuck; the second does not, and is, for some purposes, advantageous. With this chuck, all that has to be done is to place the cylinder on one end upon its face, and screw up the jaws until they grip it securely. To assist in centring accurately when independent jaws are used, there are a number of concentric circles made upon the face-plate as a guide. We had neither a self-centring chuck nor a chuck with independent jaws, but merely a face-plate or circular disc of iron screwed to the mandrel, in which there were four slots, and in these there were clamps—mere hooks which could be drawn down upon the work by nuts underneath. These held the cylinder down upon the chuck by means of the flange, to which the cylinder cover had subsequently to be attached.

To begin with, we had a good look at the casting, testing it with a small T-square, to see whether either of the flanges was more accurately at right angles to the bore than the other. Finding it to be so, we first clamped down this one on the face-plate, getting the bore to run as true as we possibly could, and then we faced up the outer flange as true as possible. We then reversed the cylinder, putting the corrected flange against the chuck, and secured it firmly, having first interposed a small bit of wood, previously turned true on both sides, and hollowed out to about what would be the finished size of the cylinder, which thus stood about half an inch off the metal. This bit of wood was turned perfectly level on both sides, and its object was to raise the cylinder so far off the metal that the tool could go entirely through it without coming in contact with the face-plate. The cylinder once fixed, was not removed until finished, except that the *edges* of the two flanges were afterwards turned up again. But we bored and turned off the face of the outer flange while the cylinder was on this chuck to ensure the flanges being exactly at right angles to the bore. This is of the greatest importance, because if it is not true the engine will never work well, as the stuffing-box will not be central, and the piston and its rod will not fail to rub more on one side than the other. In all work needing accuracy, it is necessary to consider beforehand exactly how you intend to carry out the work to the finish after doing part of it well; and removing it from the lathe, you will find that you have got into a dilemma, and cannot get on without remounting the work; and, try as much as you like, you never will remount it to run exactly as it did before.

Now here again we had learned by experience and by a previous failure. The first engine we tried to make was a brass one, because we considered it would be easier to turn. The cylinder was two inches by one and a half, and we drove the casting into a wooden chuck and bored it out, succeeding very fairly. We were proud of our work and took it out of the chuck to show a friend how well we had done it. We then set to work upon the valve-face, and made the ports, and, I believe, the piston. Next we had to face up the flanges and fit on the cylinder covers This seemed a very easy job. We turned a bit of wood to fit inside the cylinder, but no! it was no longer true, nor could we get it so. We then turned a cylindrical rod and drove it inside the cylinder, so that it should be turned on the same centres as the rod; but, alas! in driving it on we damaged one end of the wood slightly, and the back centre-point of the lathe did not fall into exactly the same position. We tried the face-plate, and at last we had to compromise matters and make the best of a bad job. The engine would work pretty well, but we never liked it, owing to the fact that we ourselves knew what no one else did, that it was at best a muddled job, and that the piston would not move freely, except in the exact position in which we had placed it, and other parts had to be left slack to allow a little play, or the friction brought it to a stand-still. There *is* a chuck, but we did not know it then, on which a cylinder can be truly remounted, but the best way by far is first to true up one flange, then to lay this on the face-plate and clamp it down securely, and never to take the cylinder off again till the bore is finished and the other flange turned. The edge of the flanges are of no real importance; the first can be turned when that flange is faced, and the other before removing it from the chuck, after having otherwise completed it. Every part will thus be true, and you will have, as we found, but little trouble in completing the several fittings. This was the way in which we turned and bored the three-inch cylinder of the engine which I am now describing.

As illustrations are a great assistance to the reader, and we are recording our own engineering accomplishments in order to encourage others, a drawing is given here of the various operations carried on, and of the various details of the engine itself. Fig. 18 is a section of the cylinder mounted ready for turning, and as if seen looking down upon it from above. A is the part of the chuck which screws on the mandrel. BB is the flat round part, the actual face-plate which has the slots in it. CC are the hooks or clamps by which the work is held down, and of which there are of course four. The face of the chuck is drawn at the side at H, but on a smaller scale. D is the flat bit of wood under the end of the cylinder, here represented as a board only, but in reality bored out to the size of the inside of the cylinder, which latter is represented at KK. A sectional drawing, it must be remembered, gives an object as it would appear sawn through down the centre as here, or sawn across, or

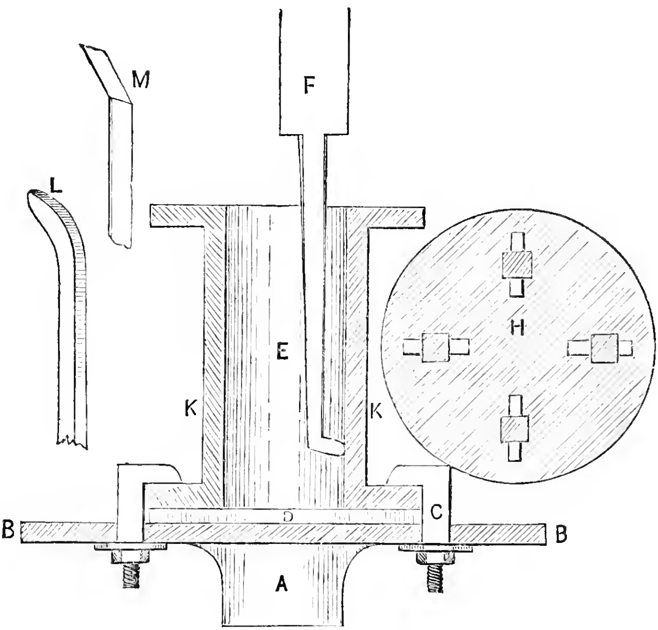

Fig. 18

sawn diagonally, and is an excellent mode of drawing to explain machinery. F is the tool, which is supposed to have almost reached the bottom. It is merely a flat steel bar to clamp in the slide-rest, drawn out into a long rounded shank which is turned to the left, and sharpened. The upper face is flat, the metal below it being bevelled off as shown at L, but the flat surface is not horizontal, but slightly tending upwards, which gives a sharper edge. This will be better understood from the sketch of a straight tool at M of a similar kind. For cutting brass this face would be left horizontal, as that metal will not be cut so well by a sharp-edged tool.

The tool shown here is represented with a round end, but for the first cut on iron a point tool is better. It takes off *less* at a cut, but it produces a satisfactory surface, consisting of a series of shallow groves of a V shape, which can, if desired, be afterwards obliterated by a tool like that in the drawing, or with a flat end. A great deal of turned work is, however, left direct from the point tool. If the feed is slow, the grooves run into each other so nearly that a level surface is to all intents and purposes produced, and as the cutting edge is so small, less power is needed to drive the tool than would be required to drive a tool with either a round or flat end. We began our boring operations with an inside diamond-pointed tool, and at last took a very light cut with another with round end, which produced a surface over which the piston worked very smoothly indeed, and which soon became very highly polished. Accuracy of bore is, in fact, of far more real importance than smoothness of surface. The latter is sure to be produced before long by the friction of the parts, even if the bore is left as it comes from the pointed tool; but if the cylinder is larger at one end than at the other, additional wear can but increase the error. Indeed, the engine never will in such case work satisfactorily, because the piston will be tight in one position and slack in another, and in the latter the steam that ought to drive it forward will of course escape round it and produce no useful effect. It might perhaps be supposed that, as the piston of an engine is packed, generally with elastic metal rings, these would expand, and so fill up the space when the larger part of the cylinder is reached. This is the case to a certain extent, but the friction is vastly increased by the powerful pressure exerted in the rings as they enter the smaller part of the cylinder at each stroke, and too much care cannot possibly be taken to make the cylinder exactly the same size from end to end.

We now had a well-turned cylinder, with both flanges truly at right angles to the bore of it, and the next thing to do was to turn up the cover or covers. There are generally two of these, but one is sometimes formed by the bed-plate when the cylinder is to be placed vertically. Ours was to take this position, and therefore we only needed one. This was a round disc cast with a short tenon to fit inside the cylinder when turned, and with a boss on the upper side to be bored out for the reception of the gland or stuffing-box through which the piston-rod

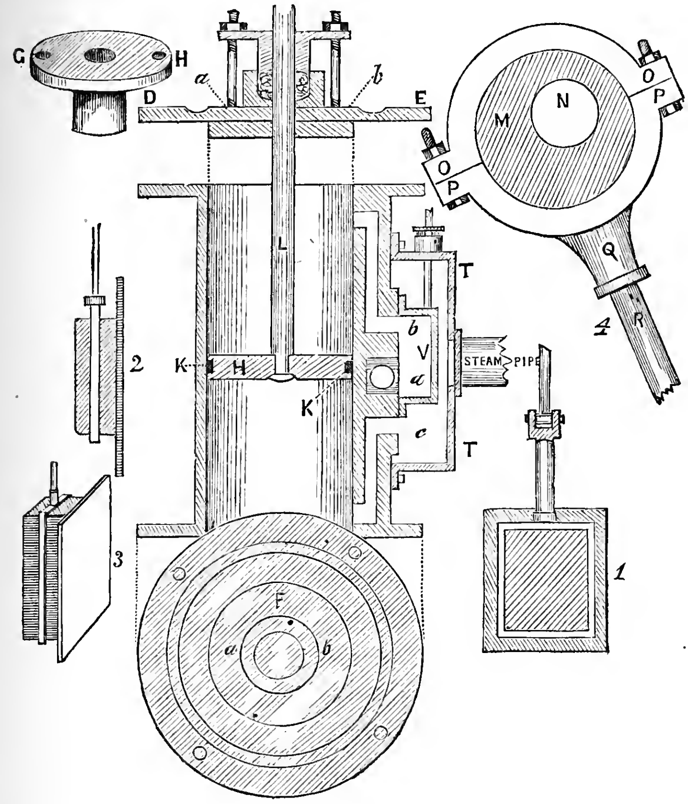

Fig. 19.

has to work. Fig. 19, DE and F represents this—F being the top view or plan, and DE the section of the same through the stuffing-box, which is shown as just ready to be lowered into the gland, where it will be held by the two studs and nuts. GF is the perspective view of this part. The space below the gland is filled with packing—either tow, or india-rubber, or patent metallic packing—but always tow in a small engine, which is forced into close contact with the piston-rod by screwing down the gland. It must be well greased to render it quite steam-tight, and it should not grasp the piston-rod so closely as to add greatly to the friction, yet closely enough to allow no steam to escape.

Now, in turning up the cylinder cover, the same rule holds good that was mentioned in respect of the cylinder itself. It must be turned as far as possible at once; it must, however, be chucked twice, as both sides have to be turned. We first turned quite truly the under side by driving the casting into a boxwood chuck, taking care that it fitted it tightly, and bedded closely down on the bottom of the hollow—*i.e.*, the bottom of the inside of the chuck. There was a second deeper hollow permitting the boss to go into it out of the way, but this was not made an exact fit, as all that was necessary was that the flat part of the cover should bed well down, and that the edge should be held securely. We now turned the first side very carefully, making the tenon fit very truly inside the cylinder, which, being finished, we could apply as a test of accuracy at any moment. Of course, we could not get at the outside edge of the cover, as it was driven into the chuck just so far as to allow the tenon part to remain outside it. We had no special difficulty in making a good fit of them, as we had now had plenty of practice.

Having faced up and completed this under side of the cylinder cover, we turned a few concentric circles upon the face of it, not deep, but about one-tenth of an inch apart; so that we could, if we chose, smear them over with red-lead and oil before screwing down the cover. This plan is commonly used in steam-engines to secure a perfectly steam-tight joint, but if the parts are faced up with perfect accuracy, no packing of any kind should be needed. We had to face ours by hand with a flat-ended tool, because there was not space enough for a slide-rest tool to traverse, and it was a very simple job, not worth rigging up the slide-rest to accomplish. The next job was to face up and finish accurately the top of the cover. This was cast with a moulding upon it, which, like many other things in this world, was for mere show, and not for use, but there were two plain flat parts upon it requiring to be turned true and level. There are but three kinds of tools necessary for brass-work—the round end, the point, and the flat tool, sometimes called a planisher. These are none of them made very keen, because a keen tool catches into brass; they therefore are ground to 90° or not less than 70°, and even when the cutting edge is 90° or a right angle, it is just eased off a little upon the hone. We had also learnt one peculiarity of brass which is often most annoying, viz., that it is given to chatter terribly, so that instead of a smooth and even surface, it is all over minute waves. To prevent this, some put a bit of leather on the rest under the tool, but the best plan is not to lay the tool quite flat upon the rest, but to raise it a little at one corner—something like the way in which a chisel is raised for wood-turning. The edge thus attacks the metal diagonally, and if a little play or spring is allowed it by the hand, it will cut very cleanly and the annoyance will cease. There is another thing or two worth mentioning here in respect of this material, which applies to gun-metal as well.

In commencing to turn brass-work, the rough outside will always be found sadly detrimental to the tool. This is because it contains numberless fused grains of sand imbedded in the metal, which are intensely hard. To get rid of these, the castings are often thrown for a short time into a pickle of sulphuric acid and water, which by its solvent property destroys this surface and renders the metal fit for the lathe. With a pickle of nitric acid or nitric and sulphuric mixed, a beautiful colour is given to rough castings, which are then dried in hot sawdust after being washed well in water, and left in the rough state, edges only here and there being turned, and burnished, and lacquered. By burnishing the cutting edge of a scraping tool for brass, a beautiful lustre will be given to the work which no emery polishing can beat. We were not, however, up to these various dodges, and patiently worked on the castings as best we might, until, by dint of labour, we put upon them a sufficiently satisfactory face.

There was no great difficulty to be overcome in facing this cylinder cover, but we had to take special care to drill it centrally to the size of the piston-rod, and then with a very narrow round tool we hollowed out to a cup-like shape the place for the gland—*i.e.*, we first turned a cylindrical hollow, and then rounded it at the bottom, so that the gland would slide accurately into it, and the packing would be pressed sideways against the piston-rod as well as downwards. For the same reason the gland itself is generally cup-shaped below in the opposite direction.

Before removing the cover from the chuck, we held a point tool so as to mark a circle a quarter of an inch from the edge as a guide in drilling the holes to receive the bolts by which it was to be attached to the cylinder. If the drawing is inspected, it will be seen that the cover has a flat part just outside the stuffing-box at *ab*, then a moulding, and then a flat part again. That marked *ab* was to take the ends of a pair of guide-bars, of which mention will be made again by and by.

The piston H and its packing KK is shown in its place in the cylinder. The packing here was of tow, wound into a groove left for the purpose in the edge of the piston. L is the piston-rod riveted into the middle of the piston, in which a hollow is made below to receive the head; *abc* are called the ports or steam-ways. One side of the cylinder is cast with a thick projection extending from one end of it to the other, and in this are cast, or *cored out*, as it is called, two channels by which steam is admitted alternately above and below the piston. These do not run into each other, but have an exit as shown. There is also a central passage, which is clear of the others and lies between them, being connected with a pipe screwed into the side of this part, whence it turns either into the air, into the chimney, or into a condenser, in which, in low-pressure engines, the steam is again converted into water by exposure to cold. In our engine this pipe was carried into the chimney of the boiler to increase the draught, as it always is in locomotive engines, and it is from it that the incessant puffs of steam issue with such a loud noise, the result of the high pressure at which it escapes.

M of this same drawing is the eccentric of cast iron with its ring or strap of brass. N is the hole through which (eccentric to the real centre) the axle of the fly-wheel passes. We shall speak of this again and point out its action, its object being to move the slide-valve which has yet to be described. The strap or hoop is generally made in two parts, with lugs or projections to receive bolts, by which they are again united when in their place upon the sheave M. To prevent the hoop from slipping off the disc sideways, the latter is turned with a deep rectangular groove, which allows the hoop to enter it a little way all round, or there is a pin which is screwed into and quite through the hoop, so as to fall into this groove, or the hoop is channelled on the inside and the disc itself enters this channel.

The pin was the easiest plan, and was therefore the one which we ourselves followed. It is, however, just as well in a small engine to bore out the eccentric and leave it as one piece, and, having slipped it over the sheave or disc of the eccentric, to attach to this another thin disc on each side; or, lastly, to turn the disc so as to leave one rim standing up, and then screw on one disc only on the opposite side.

In all such matters as this there is a vast difference between a model and a large engine. The latter has to be constructed so as to give to all parts the greatest possible strength combined with the necessary freedom of motion in the moving parts. In a model, *friction* is the great drawback to success. A very little will often suffice to prevent the machine altogether from working, and in every case it consumes by far the greater portion of the power, so as practically to preclude small engines from doing useful work. Nothing will counteract this except careful fitting and ample lubrication, especially in respect of the piston and slide-valve. In very small engines the stuffing-boxes are left wholly without packing, and a very little tow or cotton is all that can be allowed round the piston.

With the cylinder, however, as large as the one made by us, useful work was really possible, although such a small engine cannot be worked with economy. The same cost for fuel which will produce a given amount of power in an engine with a three-inch cylinder will suffice for a cylinder twice as large, and with twice the effect. Engines of small cylinder surface are generally driven at a very high speed, and are worked at high-boiler pressure; but those of large cylinders, such as are used in Cornwall as pumping engines for mining purposes, and which are usually on the condensing principle, are worked at low pressure, and very slowly indeed. Massive engines, again, are fitted with cylinders of large diameter in proportion to their height, and the stroke being very short, they are, in screw-steamers especially, worked at great speed; but they are almost always condensing engines, not high pressure, like land and locomotive engines.

As we have drawn an eccentric and its strap, we may as well say a word or two more about it, for it is an essential part of every engine. It is, in point of fact, only a crank, but usually of very short throw or traverse. Whether it is a fancy or no, the eccentric appears a much more smoothly working contrivance than an ordinary crank, and yet, if the pin of the latter were to be greatly enlarged, it would become one. The eccentric stroke is twice the distance between the centre of the disc and that of the crank shaft, or between its real centre and that which is used as such; for if the drawing is inspected, it will be seen that the hole for the axle is a little on one side. The object of this part of an engine is to work the slide-valve, which only has a comparatively short traverse, and whose office is to close and open alternately the ports of the engine so as to admit and cut off the steam. This valve is like an oblong box with a broad rim round its edge. When placed in the middle position, it covers all three ports, the central one being covered by its inside or hollow part, and the top and bottom ports by its broad rim or flange. Outside it is entirely cased in by a large box called the steam-chest or valve-casing, and into this the steam is admitted by a pipe from the boiler. When all the ports are closed, this steam cannot get into the cylinder at all, but when by the rotation of the crank-shaft the eccentric comes into action and causes the valve to slide down or up a little distance, either the upper or lower port leading to the cylinder is opened, so that steam can pass through it into the cylinder, and at the same time the other two ports are connected by both being inside the valve or box, so that the steam can escape by that port into the valve, and out again by the middle port into the air or into the condenser.

I have explained this because I remember well how, as a boy, the action of this valve puzzled me, and how, in every model I attempted at first to make, I tried to follow some other easier plan; yet after all it is a simple method, and an inspection of the drawing will render it clear.

TT is the valve-casing or outer box into which steam from the boiler passes by the steam-pipe. Now if V, which is the slide-valve, is inspected, it will be seen that *inside it* the ports *a* and *b* are connected, but not *c*, which is, however, open so that steam can enter it. This steam too, getting under the piston, will force it up in the cylinder, and any steam or air which is above it will go down through the upper port and into the slide-valve, and thence into the middle port, and so escape. Just before the piston gets to the top, the rod of the eccentric moves the valve down so far that the lower port and centre one come into connection inside the valve, while the top one is now open for steam to enter the top of the cylinder. It will push down the piston, therefore, while the steam underneath it from the last stroke will escape into the middle port as before. So by the slight movement of this cleverly-arranged slide-valve, the alternate up-and-down movement of the piston is secured, and the engine kept at work. The outer box or valve-casing has its stuffing-box just the same as the cylinder through which the valve rod passes steam-tight. This rod is the same as that marked R on the eccentric, but drawn to a much smaller scale.

It is necessary, of course, to make the valve move steam-tight, but very smoothly upon the surface on which it slides, or else steam would get under it and interfere with the working of the engine. This is one of the difficulties to be mastered in making, and this is how we succeeded. The valve was brass, and we first of all filed its face as level as we could, trying it by a straight-edge or thin steel rule (the blade of a square). When it seemed to be quite level, we finished by rubbing it on an old school-slate, which brought it very soon to a beautiful face. We wetted the slate during the process. Then it was necessary to get a similar face upon the part on which the valve was to work. It was more difficult, simply because the surface was larger, but we did it in the same kind of way, first filing and then rubbing down, and we took great care to keep the face of the part parallel to the inside or bore of the cylinder.

In every case, nevertheless, a little play must be allowed to the slide-valve, which must be so attached to its rod that the latter does not in the least tend to lift it. The steam pressure will keep it close if it is allowed to do so.

There are several methods of doing this, but we followed that commonly used in locomotive engines, and shown in the same drawing at Nos. 1, 2, and 3. This is a frame of iron, left white in each of the sketches, which it will be seen spans the whole of the valve, and into a boss on which the rod is screwed: 1 is a view from the back; 2, from the side; 3, a perspective view, which will assist also in rendering more clear to the reader the form of the valve itself, with its broad flange acting as a cover to the ports. This frame fits round the valve, but quite loosely, so as only to move it up and down, but not so as to hold it. Thus the steam can act freely in pressing it against the valve-facing. At fig. 4 is seen a hinge which allows free play to the eccentric rod, and by which, when expansion gear is not used, but the valve worked direct from the eccentric, the valve can be moved without the intervention of any guides. This, however, brings a little undue strain upon the stuffing-box, and consequently the frame has often a second rod and stuffing-box on the opposite side, which of course keeps the rod in a direct line. But we were not content with either plan. We made ours to reverse, and to cut off steam at any part of the stroke, by which we entailed upon ourselves the trouble of fitting two eccentrics instead of one, and also some levers which this action renders necessary.

Let me explain, first of all, about this cut-off system, commonly named *expansion gearing.* In a high-pressure engine, the steam may be entering the cylinder with a force of forty, fifty, or a hundred pounds pressure on the square inch, giving to the piston, according to the number of inches of its surface, a great degree of impetus. Economists have argued that there is not the slightest occasion to continue this impetus throughout the whole stroke, but that the steam may be cut off before it is nearly finished, and allowed to continue its action on the piston by its expansive force, which, though it will of course gradually get less and less, will suffice to drive the piston forward. The steam is therefore admitted at full power for a second, and then the valve moves and cuts it off altogether, and the piston continues its journey under a diminished pressure, until by the opening of the other port its action is reversed.

Locomotive and marine engines are always fitted with expansion gearing, but not generally speaking farm engines, and it is not commonly applied to fixed engines, unless of a very large size. A good deal depends on the price of fuel. In coal districts, where it is cheap, economy is not much studied, but where the supply is more limited, it becomes very important to reduce in every possible way the quantity required to work a steam-engine.

It is evidently, therefore, a great object to do this in ocean steamers, which have to carry their supply of coal on board, and which have, perhaps, long voyages to make, with no opportunity of renewing their stock of fuel.

Our own object, however, in using expansion gearing was a very different one. It was solely because we wished to make our engine as perfect as we could.

I have spoken also of reversing action, which, as all young travellers know, is absolutely necessary in a locomotive, which they will, no doubt, have frequently noticed as capable of going backwards or forwards at pleasure; and they will have also probably noticed that the engineer in charge, when desiring to change the direction, pulled towards him or pushed from him a handle. This handle is connected by levers with a pair of eccentrics on the crank axle, one being the forward, the other the backward eccentric, either of which can be brought at pleasure into gear with the rod of the slide-valve.

This link motion is shown in fig. 20. BC are the two eccentrics, keyed on the same axle, D, side by side, but at right angles to each other as regards their throw; EF are the eccentric rods, which are pivoted at G to a pair of lugs, one at each end of the link L, which is suspended at R from a cranked lever OAR. A is the fixed point on which this lever turns, so that if the handle is pulled back, it will pull up the link with it, raising the end G

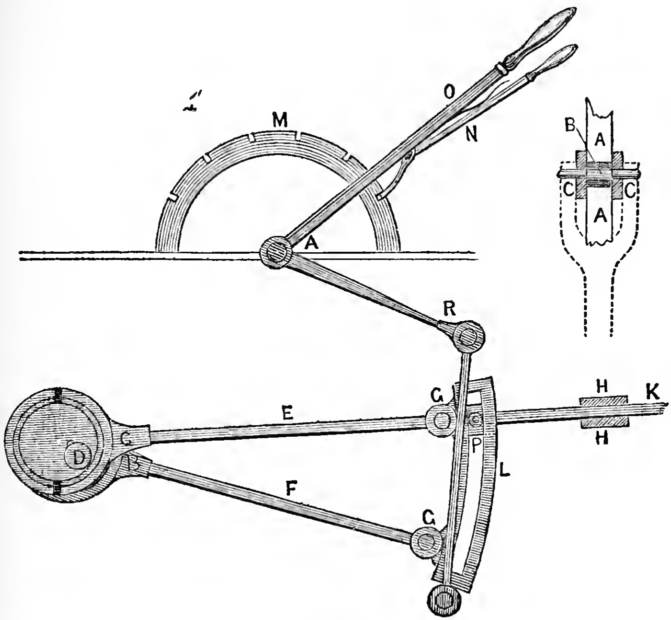

Fig. 20.

of the eccentric rod E, and also that of F. K is the rod of the slide-valve, working between guides, HH; but if there are two stuffing-boxes to the valve-casing, these are not required, as their object is to cause the rod to move in a right line. M is an arched piece of iron with notches in it, into which falls a spring catch N, connected with a secondary handle near that of the main lever, being pivoted to it.

Now it will be noticed that EGK are in a line, and that the motion of the eccentric C will be imparted directly to the valve-rod, just as if the whole were a simple eccentric and valve-rod, but the lower eccentric rod in its present position will only cause the link to vibrate without moving the valve-rod at all. There are other forms of link used, but this is the most common. To reverse the engine, the lever D is pulled back until the other eccentric comes into a line with the valve-rod, and by drawing back D, or pushing it forward to a short distance only, securing it by the spring catch N, the traverse of the valve becomes limited, and the steam is cut off at any desired point of its stroke. If this drawing, which represents the levers as they would appear in a locomotive engine, is turned so as to place the letter B and eccentrics at the bottom, it will exactly represent the link as applied to our engine, in which, as will be described by and by, the cylinder was placed with its stuffing-box downwards, and the crank axle was down below it, which is a capital plan, as the more the weight is placed at the bottom, the steadier an engine will work. It makes no sort of difference whether or not the cylinder is horizontal, or in any other handy position.

The reason that a link motion serves to reverse an engine is this: When the piston is equally in the middle of its stroke, where we may suppose it to have arrived at the time the steam was turned off and the engine stopped, it is evident that it will be ready to move indifferently in either direction according to whichever side steam is first admitted. By the way in which the eccentrics are fixed, one will be ready to move the slide-valve in one direction and the other in the contrary direction, and this link enables the engine-driver to throw either into action at pleasure. He has consequently power to admit the steam to either side of the piston as he pleases, or to stop the engine by drawing up the link till the slide and stud P of the slide-valve rod falls half way between E and G, when the motion of the eccentrics will only cause the link to oscillate upon P without moving the valve-rod at all.

It must be clearly understood that the only union between E and K is by the link—the piece P being attached to the valve-rod, and the link sliding up and down upon it. The link is attached to E and F permanently at GG. When, therefore, the link is raised by the levers, the eccentric rods go with it, but PK do not. The arch M is fixed to the bed-plate in a locomotive, and occupies a place close to the engine-driver's right hand, so that it is not situated, as here, over the eccentrics, but a long way behind them; and the connection is made with the bell crank A, by a long flat rod, which would be attached at about the point ON, and this would not be the handle, as represented here, but only a cranked lever. This is one of the cleverest inventions connected with a locomotive, and is now also applied to engines for many other purposes. It works easily, is not liable to get out of order, and enables the expansion principle to be carried out to great nicety. The arch is here represented as single, but in practice two are placed side by side about two inches apart, and the lever works between them. All these levers are flat bars with forked ends, and we made ours in the same way, filing up all of them, or grinding them on emery wheels where perfect surfaces were not needed.

In making a working drawing of this part, to get the proper curve of the link, which is, however, sometimes made straight, we struck the arc from the centre of D the crank-shaft, which brought it as nearly as possible correct, so that it worked smoothly. The slide P, it is evident, must fit and yet not jam in the link. It was made thus: The end of the valve-rod was forked so as to span the link, and the plate P, of which the hindmost only is shown, but on the near side is a similar one. The circle at P is a pin, which is turned to fit nicely between the sides of the link, and which extends through it. It has a shoulder turned down, and the tenons thus formed are screwed, and the flat plates are then screwed to them. The small fig. 2 will make this clear. AA is one side of the link, B the round piece of iron or brass turned with tenons, on which plates CC are screwed or riveted. At P is seen one plate, which, as the dotted continuation of the lines shows, goes across both sides of the link; and the similar plate represented as removed would be on this side. The rounded part, therefore, alone is between the sides of the link, and will move up and down freely in spite of the curve, which is as easily traversed as if it were straight. The forked end of the slide-valve rod is dotted, and merely to show that it spans the plates, and is attached to the same tenons as they are. It would of course be in reality standing straight out towards the spectator, and not hanging down as drawn; in fact, it could not occupy the latter position, because it is held up by the guides.

It is now necessary to say a few words about the action of the eccentric. Its entire traverse or stroke is, as stated, twice the distance between the real centre of the disc keyed on the shaft and the centre of the latter, and this is exactly the traverse it will give to the slide-valve. In setting it out, therefore, the two centres, *i.e.*, its own and the centre of the hole to be made in it for the crank-shaft, are to be the same distance apart as the stroke of the valve in either direction—*i.e.*, the width of the port and a little over—a very little, so as to make sure that the valve will cover it, and travel just beyond it before the motion begins in the opposite direction. All crank action is alike in one particular, whether produced by eccentric or otherwise. The action upon a slide actuated thereby is not of equal speed throughout, being greatest when in the middle of the stroke, and least when at the ends. This is not a great drawback to its use, as it is counterbalanced by its extreme handiness in other respects. The eccentric, considered as a crank, must be at right angles, or nearly so, to the other crank driving the fly-wheel. Its *greatest* throw must be at a time when the other crank is at its least, or on the dead centre; but the eccentric having to begin its work of opening the valve a little before the piston is at the end of its stroke and the crank in the position named, it is set forward a little upon the shaft, instead of being quite at right angles to the other.

Having entered almost necessarily into explanations of the action of eccentrics and of link motions, we must now go on to state how we actually made these portions of our engine. We left off at the boring of the cylinder and fitting of its covers, with the facing up of the valve and its seat. The valve-casing and its cover was merely a matter of filing and neat fitting—the gland being small, was cut with a thread outside, and screwed into its place, the boss being drilled and tapped for that purpose. We just ran through the boss a drill the size of the valve-rod, and followed it with a larger, which was carried down nearly to the bottom, but not quite, so that it made a recess, of which the bottom was tapering. The proper tool for this sort of work is a re-centring or pin-drill, *i.e.*, a drill with a projecting end, which goes into the hole first drilled, while its edges cut the cavity larger. This ensures the cavity being concentric with the hole originally made. These pin-drills are used very extensively in the mechanical trades to form countersunk holes for cheese-headed screws, and should form part of every amateur mechanic's stock in trade. If our readers go to the gunmaker, he will show them several kinds of this useful tool, which he uses to a very great extent. They will be found also at any machine-shop, but not always at tool-shops, as most workmen make their own, because they are required of all sorts of odd sizes, and there is no standard size recognised, as there is of other drills. Not having any, and, in fact, never having seen one, we did our work as stated, and made a satisfactory job of it.

In making this engine and many other things, we had occasion for a number of six-sided nuts, not that square ones were not a deal easier to make, but the hexagonal form was vastly to be preferred, as more correct in design theoretically as well as practically. In the days which I am speaking, bolts and nuts could not, I fancy, be purchased ready-made of all sizes, as they can now, and we had to make our own, with a screw-plate to cut the threads. Now a six-sided nut is a difficult customer to deal with, and needs very careful filing to get it true and even. We accomplished it thus :—We cut a notch in a bit of tin with an angle of 135°, which we got at first by dividing a circle into six equal parts, and connecting the points of division by straight lines, so as to represent a six-sided nut; cutting out this, we used one of its angles as a gauge, by which to cut the notch in our slip of tin. We then took a bar of iron long enough to make six nuts, and we filed it up to six sides by help of our gauge. We then sawed it off with a hack-saw into six equal pieces, each of which we afterwards drilled, drove on a taper mandrel, and turned at each end, rounding off neatly the one which was to stand uppermost. When cut off, and while still upon the mandrel, we touched up each nut with a smooth file to give it more perfect finish, and we thus made all our nuts precisely alike. We then placed them in a vice with lead clamps to prevent bruising them, and drilled them half from one side and half from the other, running a broach through afterwards to equalise the holes ready for the taps. The shanks of the bolts were turned by hand with a graver, and finished with a file, and they were cut from rods sufficiently large to allow of being filed up to six-sided heads; but we gave up this as entailing unnecessary labour, and generally turned the heads also in the lathe and left them round. Thus made, however, they were liable to turn round and round in their places while the nuts were being screwed up; we therefore cut a nick across the heads for a screw-driver, by which we could hold them until they got a bite upon the surface of the parts where they were placed, after this they could be tightened without turning.

The handles ON were just the parts that, if well-made, add much to the appearance of an engine. We made them therefore of round iron, centred and turned up at the handle end to a nice shape, and then filed down neatly, the flat sides being rounded in a hollow sweep into the turned part at A, where the pin goes upon which it turns; we also finished the top in the lathe, but the end R being forked to receive the end of the bar which is attached to the link, we made it of a separate piece. This was turned on a taper mandrel first, to face up its two round sides, and then, having bored and tapped the other part by which it was to be attached to its arm, we mounted it on a chuck with a projecting centre-screw to fit it, and thus were enabled to turn up the neck as well.

Wherever a fork of this kind occurs, if it is large enough to turn, it is better made as a separate piece, unless the arm upon which it occurs is a very short one. This arm, when the boss is mounted in the lathe, flies round and round with great rapidity, and endangers the knuckles, or even the face, especially if the turner is short-sighted, and obliged to look closely as his work proceeds. It is in making *small* models that these parts give most trouble, especially if the lathe is not one that runs lightly and easily. It may be taken as a general rule that the lathe should be suited for the work, and that not only cannot heavy work be accomplished on a light lathe, but that light work cannot be done on a heavy one, as may be easily proved by turning a set of studs in a six-inch lathe, such as is usually fitted with back-gear for metal work. It will be found altogether too sluggish and heavy, with too much impetus when once speed is got up, and too little at starting afresh after stopping to inspect what has been already done. Having experimented upon shirt-studs with just such a lathe, I speak from experience; at the same time it is absolute bullying to turn heavy work and to use heavy chucks upon a really light lathe fit for ornamental turning. I do not say that it cannot be done, for I have seen the naves of farm cart-wheels turned upon a three-inch centre-lathe, propped up to six inches with a block of wood permanently fixed under the poppit. It took in the work in this way, but it is easy to understand the strain upon a mandrel and collar designed only to carry work of the very lightest description. No doubt it has long ago been worn out and descended to the scrap heap.

The discs of the eccentrics do not in the drawing show the mode in which they were turned. They were, in fact, bored first through the real centres, and turned and faced up on a mandrel. This hole was of no importance, as it did not interfere with that for the axle, and it was consequently left, and not plugged up or concealed. A groove was turned in the edge of each disc to receive the pin or pins; for there were two spoken of before, and shown at opposite sides. They had no heads, and were sunk to the level of the brass hoops, so as not to project. They did not, of course, show at all, but are drawn as if the disc was a section, the dotted line being supposed to be the bottom of the groove. The eccentric hoops in this case had no lugs, and were cast and made in one piece, which was mounted in a boxwood chuck, that had a place cut out to receive the projecting part C, and carefully bored and faced on each side; and while the latter work was being done, a line was traced with a point tool as a guide for subsequently filing to a true circle concentric with the inside the outer edge of the hoop, which could not be turned on account of the projection C, unless, indeed, the lathe were fitted with a segment stop by which the rotation of the mandrel could be arrested at any point. This, however, was a complication which our lathe did not possess, and we filed the brass up to the lines traced on each side, and then rounded off the angles to give it a nice finish.

The link LL was made of a plate of iron a quarter of an inch thick, filed down to three-sixteenths. We first cut out this link on paper, and gumming it to the iron, marked it all round with a finely-pointed centre-punch. We marked it on a piece not much broader than needed, and before shaping it on the outside we drilled holes all along the slot, which we threw into one by a rat-tail file, and then finished by carefully filing all over. It was a somewhat tedious job, and required care to get the faces true and square to each other, but we accomplished it at last by not hurrying over it, and we got the angles all sharp, and the surfaces flat; and when finished and in place upon the engine, it looked exceedingly workmanlike. We also managed to fit the joints of this link motion and its levers, so that they worked nicely without being too slack and shaking about, as they often do in model engines. All this required care and patience, but in our various attempts at mechanical manipulation, we had acquired a fair degree of both, and were seldom guilty of hurrying our work, and thereby spoiling it.

The semicircular notched plates were cut in a similar manner out of a bit of lock-plate, but for these, of which a pair were made, we took advantage of the lathe. We clamped upon the face-plate, on a bit of board placed to allow the tool to cut quite through without coming in contact with the face-plate, the bit of iron plate, and with a tool fixed in the slide-rest cut out its centre so as to leave a ring, of which, however, the outside was of course square. We then cut out this again, at a width sufficing for the pieces we required, so that we produced now a circular ring of flat metal, which fell off as soon as it was completed. We then marked the diameter and sawed it into halves, which we fixed together in a vice, and drilled for a pair of studs at each end, which were turned with shoulders, and riveted into the plates at each end, to keep them a given distance apart. Before the rivets, however, were put, and while still clamped together in the vice, we filed the notches so that they should exactly tally with each other. I had almost forgotten, however, one important part of the proceeding, viz., heating the ends and screwing them in a vice, in order to bend up a little bit to receive a hole for a screw, by which the pair when finished were attached to the bed-plate in which they rested. This bed-plate was fixed to the boiler, which was a vertical one, in the manner we shall by and by describe. This boiler, however, we decided not to attempt ourselves, because we wanted to put a good amount of pressure upon it, and did not feel certain of our capabilities in regard to riveting and fitting it. It was, however, made to our own plan, and got up steam and kept up the supply very well indeed.

The boiler, as will be seen from fig. 21, was cylindrical, but stood upon a square base in which was the fire-grate. This consisted of a grating which sloped slightly upwards from the furnace door. The latter was on the side opposite to the cylinder and fly-wheel, so as to keep the dust and dirt from the working parts as much as possible. A circular flue from the back or nearly the back of the grate went entirely through the boiler vertically, forming a chimney at the top, and into this the exhaust steam was carried by the pipe P, which turned upwards in the funnel. The other pipe just below it brought the steam from the boiler into the steam-chest of the slide-valve, which being at the back, is concealed from view by the cylinder.

M is a tap for drawing off the water of the boiler, and was of large size to enable it also to carry off any sedi-

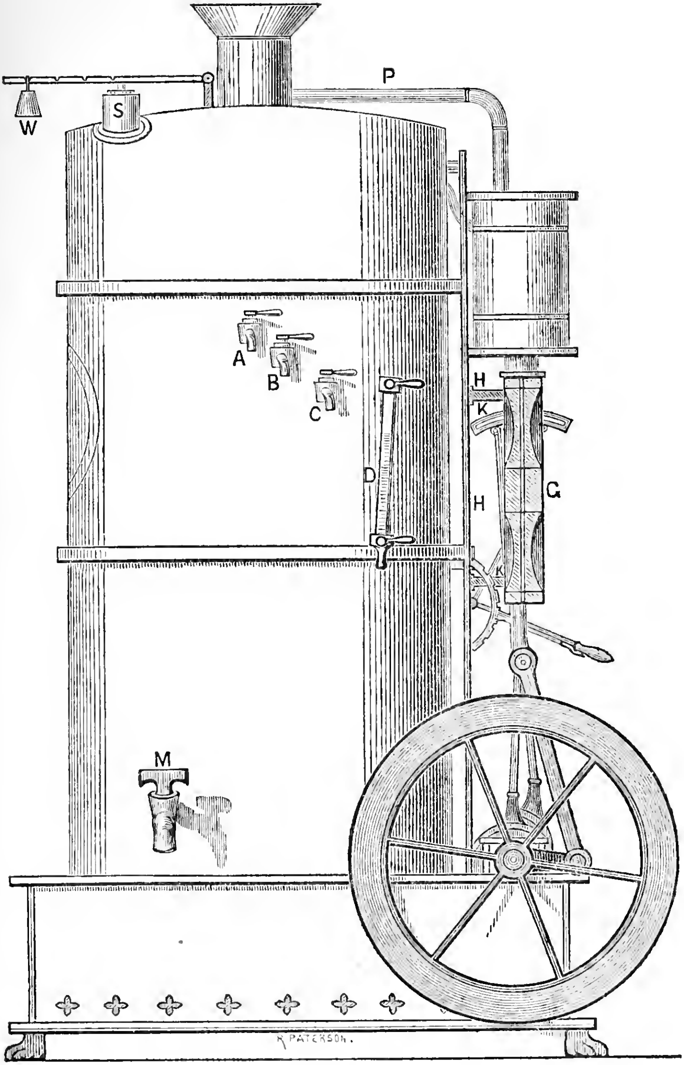

Fig. 21.

ment which, settling at the bottom, would prevent the heat of the furnace from exercising its full power upon the water. ABC are gauge taps for the purpose of testing the height of the water, and D is the glass water-gauge for the same purpose. We made the gauge, but not the taps, which were easily procurable from the gasfitters. S is the safety-valve with its lever and weight. The latter, hung on the outer notch, registered a pressure of fifty pounds to the square inch, we seldom worked at a higher pressure than twenty-five pounds, but the boiler was tested and considered safe at eighty pounds. The cylindrical part was of copper, the lower part of iron plate, the two fastened together with a circular row of rivets, a layer of red-lead being interposed. To stiffen the whole there were two wrought-iron rings turned up bright, and partly on these, and partly on a pair of short pillars, rested the bed-plate HH, to which the cylinder and other parts of the engine were bolted. The bearings of the crank-shaft, however, were on the top plate of the iron base, the fly-wheel being outside.

The row of ornamental holes on the lower part were merely to admit more air to the fuel, which was charcoal with small bits of coke mixed with it. The reversing gear is partly visible, and needs no further explanation than what has been already given. G is the outside of one of a pair of guides of cast iron, the inner sides and edges of which were filed up very truly to receive the gun-metal block attached to the end of the piston-rod, to cause it to move in a perfectly straight line. These were supported by pillars, KK, screwed into them and fixed to the bed-plate. The fly-wheel was of cast iron. This we could not ourselves turn, as it would not go into our lathe, but a friend faced up the rim on all sides, and also the boss or nave in the centre, which gave it a nice finish. The rest was painted over with dark green and varnished, as were also all parts in which the castings remained in the rough state. This engine gave us fully one quarter-horse power, and I think would have given more if the grate and its fuel had been better arranged.

In a previous page, speaking of the method we adopted to face up our slide-valve, I remarked that it was not the right method of doing it. Before concluding the present chapter, therefore, I will say a few words upon this subject, which in practical mechanics is of such extreme importance.

There is hardly a machine in use which has not one or more flat surfaces, upon the absolute truth of which its action more or less depends. The face of a slide-valve and of its seat is but a case in point.

Before my young readers or their parents were born, the only plan which was available was to use a chipping-chisel, and to follow it up with the file, first with very large and coarse ones, and then with lighter and finer, until something approaching a level surface was obtained. Then, if greater accuracy were needed, and especially if two level surfaces were intended to work together, they were coated with emery and oil, and rubbed to and fro, until both surfaces had attained such perfection as this method was calculated to produce.

This in time made by no means a very bad surface, and for years was considered amply sufficient to meet all circumstances. It had, nevertheless, certain drawbacks. In the first place, the emery got imbedded in the face of the work, and the surfaces continued to grind and abrade each other long after they were supposed to have become quite clean. Then, again, as metal is seldom equally hard at all points, the emery ground the soft spots more than the hard ones, and consequently the surfaces were very rarely as perfect as they were supposed to be, although for want of better means they were of necessity used in that imperfect state. At last came to the fore one of our greatest living mechanics, now known in all lands as Sir Joseph Whitworth. I wish I could tell you, boys, about his life, but I have not much doubt that, like all our greatest and best men, he had to fight his own way, and gained his present proud position by dint of downright (and upright) hard work. For men are only born mechanics in one sense, and that a limited one—they are born with mechanical tastes and predilections.

We can't tell how it is, but Providence has given to nearly every one a liking for some one study or pursuit beyond all others, and if those likings are duly cultivated by study and diligent practice, they will profit not only the possessor, but the world at large.

Now, the mistake which many of our mechanical boys make is this: They think mechanics so natural to them that hard work, especially hard reading, is unnecessary. The consequence is, they remain always at the same level, they just muddle along, playing at mechanical work, but they never do any good with it.

To make the necessity of study more clear, let us suppose one of our young friends desires to make an engine or a machine to do certain work. It is not enough that he has devised in his own brain a certain vague plan, but he must reduce this first to a very accurate working drawing, *i.e.*, a drawing in which every detail is clearly set out to a certain definite scale, so that if the parts of the machine are made by that drawing, they will fit into their proper places, and work as they are intended to do. Now, the first question is as to *size* and then proportion. The different levers must be large enough in order that they may have the requisite strength, but they must not be too large, so as to waste material and add unnecessarily to the weight and to the cost. To determine this point alone, much theoretical knowledge is necessary. The strength of bars of iron of a given size and shape must be known, both in regard to their ability to stand a strain tending to bend them, and also in many cases tending to twist them or to crush them. The question may arise whether a bar should be of a square, or oblong, or circular, or elliptical section; whether steel, or iron, or brass is preferable; whether it should be of cast or wrought metal; and without technical knowledge of the nature of these materials, the question must be decided by rule of thumb. What is the result? Perhaps you complete a four-horse engine, and the connecting-rod is only strong enough for one-horse power; or the expansion and contraction of the metal under different temperatures having been lost sight of, rivets loosen and plates crack; or the moving parts are so unduly heavy that half the power which ought to have been useful is expended in giving them motion.

An engineer must have a whole lot of this sort of information at his finger-ends, besides the more ordinary elementary knowledge of the laws which govern nature. He must not only be able to do certain work in a certain way, but to know why that way is preferable to any other; and he must have an immense deal of general knowledge which I cannot now stay to detail.

Then comes manual practice, the handiwork part of the question; and I know of no detail of mechanical work which will more entirely prove the necessity of such practice than that now under consideration—the production of a level surface. Looking at a skilled mechanic using a file, any one would imagine that a very short apprenticeship would teach him to do the same. I can only say, Let him try it; and in five minutes his self-assertion will have taken flight, and he will have been taught an important lesson about his own ignorance that will do him a great deal of good.

To file a level surface is, in fact, a test of skill of so high a class that not many will do more than barely pass muster in respect of it. The first necessity is, to have tools of accuracy to test the work as it proceeds; the next, to have properly selected files; the third, to have a good scraper, sharp and well hardened, to follow the smooth file.

Of tools of accuracy required, the first is a steel straight-edge, perfectly true and reliable; the second, a surface-plate, large enough to allow the work to be tested to lie wholly upon it; the third, a set-square; the fourth, a scribing-block. With these you are fitted up for real work.

The straight-edge is merely a steel rule, the sides of which are truly parallel to each other. Sometimes, as in those now imported from America, they are graduated in inches, with subdivisions, ranging, if required, to sixty-four in the inch; sometimes they are without these. The graduated straight-edges are about one-eighth of an inch wide, and may be had from one inch to two or three feet in length. Workmen, however, usually make their own of steel less than half this thickness. There are also straight-edges much broader—say one inch wide, with a rib on the back to stiffen them. These are of cast iron, and beautifully got up on the face, but are not nearly so common as the first named, except in the large sizes. The surface-plate is an extended or very broad straight-edge. They are of all sizes, from six inches square upwards. They are of cast iron, ribbed on the back to keep them perfectly stiff, and with two handles, and feet to rest them on (at the back), because, being tools of perfect accuracy, all possible care must be taken to make them so stiff and strong as not to yield in the least in whatever position placed; and this is practically a great deal more difficult than the tyro would suppose.

The set-square is of steel, and is simply a very accurate one cut out of sheet steel, or it is made with a broad back, so as to stand upon the surface-plate without being held, which is often very convenient. Sometimes, however, this tool, instead of being of the usual form, is extended in width on both faces until it becomes like a sheet of note-paper opened to a right angle, or a long strip of card folded lengthwise to a right angle, and filled up in the angle by cast ribs, both surfaces thus forming accurate

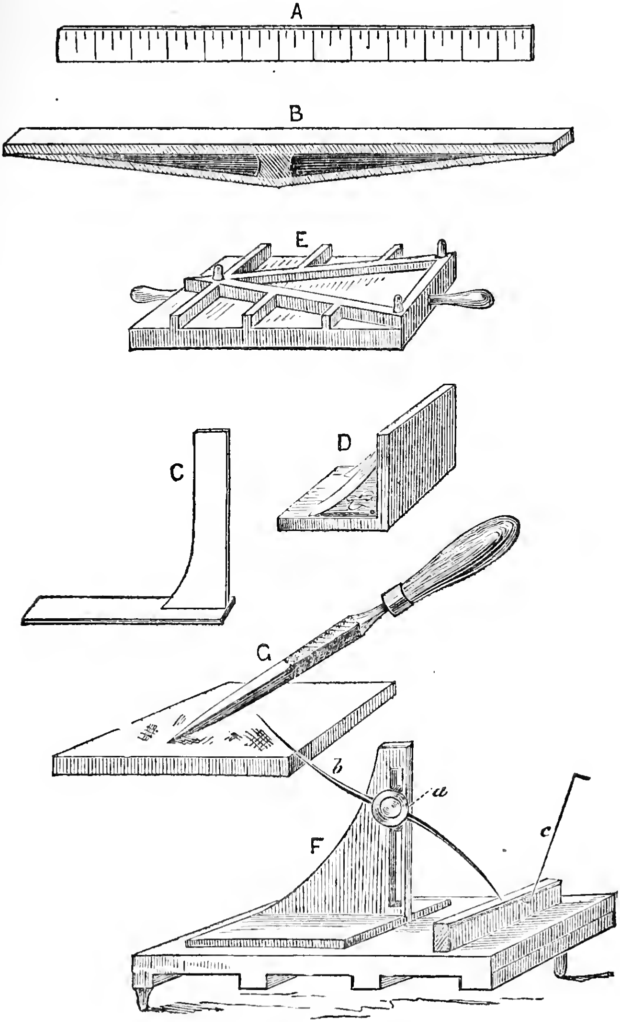

Fig. 22.

surface-plates. These are, of course, more costly than the ordinary steel square, and the tyro need not buy one; but they are very useful in machine manipulation. These we will illustrate presently, as the next will perhaps hardly be understood without a sketch.

This is the scribing-block or surface-gauge always used in connection with the surface-plate, and represented at F of this plate. To return, however, to the straight-edges: A represents the simple form, B the ribbed and broader kind, of which the face used for testing is here shown upwards. There is, in the longer ones, a flat piece or foot at the angle where the inclined ribs meet on purpose to stand the tool upon when not in use. C is a square made so as to stand by itself, and D a plate-square for testing broader surfaces. This may be of any size, and is often made much longer in proportion to its width than represented here. E is a surface-plate turned upside down upon its face to show the ribs by which it is stiffened at the back, and the handles by which it is lifted. Its three feet are also shown.

The face of this is worked so true and so absolutely level, that if one is stood feet-down upon the bench, and another lowered upon it, the top one seems to float upon a thin film of air shut in between them, and can be spun about in all directions with a touch; but if the upper one is slid on from one edge, instead of being lowered down direct from above, it will pick up the bottom one if it is lifted, as they are pressed together by the weight of the atmosphere, there being no air between them to counterbalance that pressure. They are made exactly in the way presently to be described, by which all surfaces are now got up at the best engineering workshops.

The scribing-block F, also used with the surface-plate upon which it stands, is perfectly level underneath, and the slotted plate is at right angles to the base. This plate carries a short slide, which works up and down smoothly in the slot, and through which is a screw, with a slit or hole in it to receive the bent needle or scriber *bc*, of hard steel. This can be raised, therefore, and turned about at pleasure, and a turn of the milled-headed nut fixes it at once in any position. The scriber can be changed for another, curved differently, and this is also so held that it can be lengthened or shortened at pleasure in either direction. There is no more useful tool to the metal-worker, who, indeed, cannot possibly do accurate work without it.

Let us consider the uses of these several appliances.

The first thing to do in working up a level surface is to see that it is not *winding*. For this we require two straight-edges like A, wide enough to stand on edge by themselves. Laying them in this position, one at each end of the surface to be tested, we look at them from such a position that the eye just catches the upper edges of both, and if these agree, we know that at any rate in that direction there is no wind. We then try another position, and if in any one we detect the error, we must file away the surface where too high, and get the whole as true as we can in respect of that error. We next proceed to face up one side, the one which we have corrected thus far. If there are any projections much above the level, or if it is a casting, we commence by using a chisel, called a chipping-chisel, with which we remove all the hard skin of the iron, and all the larger prominences. Then with a coarse file we remove the rough edges left by the chisel, and work all down to a tolerable level, and in this operation we test the surface in all directions with the straight-edge, looking under it at the line of light, and noting where the metal needs lowering. Having done this so far as a coarse file will enable us, we take a bastard or second-cut file. and go over it again; and now, if we have one of the broader straight-edges like B, we rub its face with a little red ochre and oil to colour it, making a very thin layer of it; and when we try the surface now, we shall redden all the high parts, and so more easily enable ourselves to distinguish the prominences which need the file. When the straight-edge will guide us no further, and the surface is approaching a true level, we substitute the surface-plate, which enables us to test at once a much greater area, using the red ochre and oil smeared over its face as before. If the object is small, the surface-plate will be stood on the bench, and the work placed upon it; if large, the surface-plate will itself be lifted and turned over upon the work; and in either case, by a slight rubbing we mark all the high places. Now, however, we have to discard the coarser and middle-cut files in favour of the fine ones, which are to be used until it is found that they no longer can be made to localise their action sufficiently—*i.e.*, that in using them we are in danger of filing too large a surface. The file is then laid aside, and the scraper used instead, or alternately with the file. G is a scraper, made commonly of an old three-square file, ground to a point, so as to give three somewhat curved and very keen edges, which must be constantly renewed by rubbing on the oil-stone during the progress of the work. With this tool any given spot that is too high can be scraped off from any part of the surface, and minute points attacked in the centre of a large surface which no file will reach. In use, the handle must be firmly grasped in the right hand, and the blade in the left, and the whole tool may need to be steadied by keeping the elbows close to the sides, and, as it were, *hugging* the tool. The work must be held in the vice, or, if this is not possible owing to the size or shape of it, it is to be laid on the bench, and held securely by nails tacked in around it. The high parts should be scraped by square touches, a few in one direction and a few crossing them, as shown in the sketch. The surface-plate must be applied again and again, and it will redden more and more of the surface, and this, when broad, can again be filed, and then probably a few points only will be reddened, and the scraping will have to be renewed, and so on, patiently and steadily attacking the higher parts until the whole surface is found on trial to be reddened uniformly, showing it to have been reduced to a true level.

I know of no work that tests the patience like this, or which, when done, will give a feeling of greater satisfaction.

If there are faces to be got up at right angles to this first, one of these must be taken in hand next ; and here not only has a level surface to be produced, but the right angle must be accurately kept. The work has to be laid, therefore, on the surface-plate with its finished face downwards, and the square C or D brought up from time to time against the face which is being worked ; and if D is used, it may be reddened on the vertical side, and will mark the part that is not truly square ; and here again the file and scraper must be patiently used until the second surface proves to be correct. Of course the time required will wholly depend upon the extent of surface and skill or the contrary of the workman ; but all this is real work, of which not one step can be shirked or even hurried over, and in which all has to be done in regular order—first, one face as a starting-point; next, one of the sides at right angles to it; then the side next to this; and lastly, if necessary, the fourth side, and also the ends. It is, therefore, all straight sailing after all, but by no means easy work; and unless the scraper is well managed there will be scratches made, and the surface, instead of having the beautiful mottled appearance it ought to exhibit, will not be beautiful at all, but, though true, it will be unsightly. When it comes to facing up the last side, and in other cases to be described presently, the scribing-block is necessary. The block in the drawing is placed upon the surface-plate, and the scriber, which is merely curved so as to point downwards, is supposed to be feeling the thickness of the block at all parts as it is moved about on the surface-plate under its point. There are many cases in which this use of the instrument is valuable. Either the scribing-block or the work may be so moved. At present we are supposed, however, to be about to face up the fourth side of a rectangular metal block. It is evidently necessary, in order to make this side truly parallel with the opposite one, to file and scrape off the upper surface to a certain depth all round measured from the face already finished. For this purpose a scriber is put in with a point bent more nearly at right angles, like that on the right-hand side, and while the work is held fast the block is slid along it to mark a line a short distance from the edge all round the work which is the guide-line for filing. The sides to be marked should be rubbed with chalk to make the line more visible, but the scriber is of hard steel, and will scratch any metal softer than itself sufficiently to make the line show; and when the surface is levelled down to it, it must of course be accurately parallel to that on the opposite side. The scriber is thus a gauge for thickness and for parallelism of opposite surfaces, but it is also a universal gauge for which engineers find a score of uses.

Marking work ready for the file is called *lining out*, and in all work of accuracy has to be done with care before any but the preparatory processes of chipping and rough filing have been done. All the above are called tools of accuracy, and are never found, therefore, in the shops of the blacksmith, nor of many country workmen professing to keep repairing shops for engines and machinery. No lathe-maker, engine-builder, instrument-maker, or others who have to work to accurate measure, could do anything without them, and their use should always be learnt by the amateur.

Chapter X.

OUR CARVING-MACHINE.

I SUPPOSE a boy's first carving-machine is the much-coveted and ill-used pocket-knife, which, if it ever did cut (which is very doubtful, for the steel of which it is made is of the worst possible quality), certainly became hopelessly blunt after a week's possession. As a carving tool, its capabilities are usually great upon bread and cheese and cake, somewhat less upon lawful whittling of sticks, and terribly successful upon the edges and surfaces of school-desks, on which it is invariably used to carve initials and dates. Who does not remember the excitement caused by the acquisition of a new specimen of this highly-prized tool, especially if fitted with a dozen implements or so, all as a rule useless for the various purposes which they are nominally intended to serve? The eager eyes of the admiring throng of small boys allowed to inspect but not to touch—the chorus of approval as each detail is successively opened to the view—the delicate passing of the thumb along the edge of the blades, accompanied by an assurance of such keenness as few rival knives can possibly possess? Ah! boys, we oldsters don't forget these sensations of our early years, and if we now smile at yours, it is not from lack of sympathy, for we should think you very apathetic lads if you did not evince these innocent excitements. But I fear experience is already dawning even upon some of you. A few at least of the elder among you have already begun to find out that one-half of the world gains a living by cheating the other half, and that pocket-knives are but insidious wares after all—the most pretentious being generally the worst. If there are two pocket-knives at five shillings each, one with a pair of blades only, the other with tweezers and gun-pick, corkscrew and reamer, and possibly with other adjuncts, you may be sure that the first is the best, and that the last is a humbug, worth nothing at all. As a rule, you will find that, in apparently getting the least for your money, you get the most; and that if anything is to be had very cheap, it will prove a very dear bargain in the end. Generally speaking, it may be taken as a rule that good finish is not put upon a very common article, and this is perhaps specially true in the matter of knives. But you must understand what is meant by good *finish:* it is not polish, but *good fitting.* Looking down the back, you will see no daylight between the spring and the sides—no rough places; the blades will open smoothly, without difficulty, and when open will not shake from side to side upon the rivets. There will be no sharp corners to tear your pockets or wound your hands, and the whole knife will have a finished and neat appearance, and it will probably be considered dear at the price demanded for it.

In our pocket-knife-days we had endeavoured in a small way to do a little carving, but with very poor success. Afterwards an inspection of some carvings of oak that fell into our hands aroused in us an ambition to copy them with gouge, chisel, and mallet, and we found it on the whole more tedious than difficult, and, unless with figure subjects and elaborate floral designs, we succeeded in some other attempts of the kind. But we often talked together about the possibility of doing by machinery a great deal of the work then always done by hand, especially when some simple design required to be reproduced in quantity, as was so frequently the case. We heard about that time of a copying machine that had been made and used in London, but we knew nothing of its details, and could not set off in our minds a satisfactory kind of apparatus. We also wanted, if possible, to contrive a machine which should rather enable us to follow any design of our own, and which would work quite independently of any pattern, which we understood was not the case with Jordan's machine. Our difficulty was that a gouge or chisel, working either directly up and down or horizontally, or at any given angle, would not under any circumstances serve the required purpose, and yet gouge and chisel seemed to be the tools chiefly used by professional carvers, although known by other names, according to the forms of their cutting edges, and the bent or straight form of their shanks. After numerous experiments in this direction, we found it necessary entirely to abandon this line of proceeding, and to devise a machine on a completely different principle; and we eventually hit upon revolving tools of such varying shapes as were needed. Since that time an enormous amount of work, not only in wood, but in metal, has been done by revolving cutters and drills, and this method is extending daily; but in the days of which I am speaking the system was but just coming into notice, and was, moreover, not received in England with a great deal of favour. America in this, as in other mechanical innovations, forestalled us, there being apparently in that country less tenacious adherence than with us to old-established methods of work. The chief agent we perceived would be the drill, because this could be easily made of any required shape, and easily renewed if it should be broken; and what we chiefly had to do was to devise means either for moving the work about in all directions under a fixed drill, or to mount the drill itself in some sort of swinging frame, which we could so move as to cause the drill to traverse freely over the work, and to rise and fall as desired. This may appear a very simple thing to contrive, but practically we found that it required a great deal of thought, and not a few experiments, to enable us to carry the plan to a successful issue.

I believe the first thing which gave us a hint in the right direction was the constantly-recurring use of the centre-bit, which not only serves to cut a hole through a board, but, when desired, to scoop out a deep or shallow cavity only, and this, if the tool is keen, it does with very great neatness, leaving in tolerably close-grained woods a very good surface both at the bottom and side of such cavity. Carrying out this a step further, we saw that it would be easy to bore out such cavities so as to intersect, or partially intersect, each other, which would give cavities of various external forms, of which the Gothic trefoil and quatrefoil were simple examples. These are represented in the following figures, A and B, while the others are all forms producible by a centre-bit alone without any aid from machinery, it being only necessary to know just the various positions for the point of the centre-bit, and the proper diametrical sizes of the latter respectively.

In fig. 23 is shown the kind of work a centre-bit will do, and this plate contains but a few simple designs of many that can be marked out by our mathematical

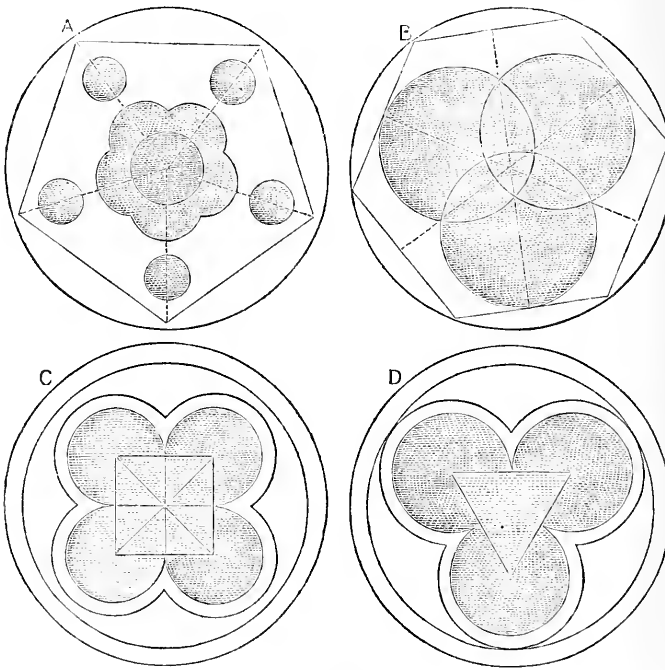

Fig. 23.

youngsters. A is a pentagon in a circle, which is the foundation of the five-looped figure called by architects a cinquefoil or five-leaved design. The lines radiating from the centre of the main circle to the angles are those on which lie the centres of the five circles which cut each other to form the figure, and their centres are on points on the circumference of the inner circle in which it is cut by the radiating lines. All this can be cut out by the same centre-bit, the inner darker circle being again cut out to a lower level. The outer small circles, the centres of which are also on the radiating lines, need of course a smaller centre-bit.

When this has been thus cut out, a five-looped recess will have been obtained, and, if desired, it might easily be inlaid with ivory if a dark wood is used, or with ebony if a light wood, as satin-wood or maple, has been chosen, and no one would guess it to have been carved by so simple and rapid a process. As a stand, for instance, for any small vase, or merely as a tray for rings, it might be made very elegant and useful, but in this case, the outer circle, or outside of the block, would be turned in the lathe, then the pentagon marked, and also the circles to be cut out. Next, the part between the hexagon and outer circle should be cut away a little, so that the hexagon may stand up above the level of the outer part, and lastly the recesses cut, which may need, perhaps, to be bevelled off at their upper edges with a very sharp chisel (used bevel downwards.) A simpler finish than ivory would be to line the whole recess neatly with red velvet. To make it into a first-class affair, a thin plate of ivory covering the hexagon, and cut to match the pattern, might be glued all over the top, in which case the wood should be black ebony or some very dark wood.

The next design to be treated in a similar manner represents a hexagon on a circle, with a trefoil inside for the recessed design, which, as the circles here left show, can also be cut out with one size of centre-bit. The generating lines of the centre points are left to show from what points the circles are struck. The other trefoil design, marked D, is in some respects better, but has not the hexagon outside it. This is the true Gothic trefoil, which is struck from the three points of an equilateral triangle, the radius of each circle being equal to half of the side of such triangle. The double lines, coupled with the shading, show the effect produced by bevelling off the recess, the width between the concentric circles (left white) showing the width of the bevel thus made. The triangle, left to show the mode of sketching the design, would, of course, be cut wholly away by the centre-bit. The outside double circle might here represent a neatly rounded beading cut in the lathe round the edge, or merely a bevelled edge (bevelled outwards).

Lastly, we have in C a quatrefoil, of which the centres are the angles of the included square, the radius equalling half any one side of such square. This worked with a large centre-bit would serve, perhaps, as a stand for four little glasses to contain violets, or on a still larger scale, as a stand for four egg-cups. Now, all these are usually done in the lathe, cut out and worked by special apparatus, of which the eccentric cutter stands pre-eminent; but, writing for boys, my desire is to show by what simple means even designs of a complicated nature can be made if skill and ingenuity are exercised in their production. The lathe apparatus will, beyond a doubt, make cleaner and more finished work, but it is not only expensive, but also delicate, and it needs more careful usage than boys are wont to give, whereas this is cheaply and easily to be done by any lad who knows how to sharpen his tools and use them.

The centre-bit will do almost any recessed work of which the outline is formed by the intersection of circles, and in which the sides of such recesses are vertical. The drawback to its use is the point which, on the other hand, is so necessary to assist the workman in placing his circles correctly that it cannot easily be omitted. The point, however, of an ordinary centre-bit, when required for such work, may be shortened so as only just to hold the cutters in position. After the whole has been, however, roughed out, a cutter of similar form, without any point, will serve to finish the bottom of the recess, and will obliterate the holes made in the centre of each circle, and level the whole of the recess uniformly.

I am now writing to a great extent in advance of our actual work, and shall continue to do so, as it seems a pity to stop short of the developments of our primitive means for carving and ornamenting work by means of revolving cutters and drills. Our first machine was similar to the drilling apparatus that has been elsewhere described (fig. 22 M.), and was fixed upon the lathe-bed and driven by a cord from the fly-wheel in the usual way. The spindle passed through two collars, and pressure was obtained by hand, or by hanging a weight on the lever, so as to leave both hands at liberty to manage the work. It was made entirely of wood, the holes in the projecting arm being bushed with brass. A good deal of lubrication was required to prevent wear, owing to the rate at which the drill revolved; for we soon found that the faster we could drive it, the better was the work produced. When at full speed, with a flat ended and a keen drill, we could hollow out a box in pretty hard wood in a few minutes, moving the work about in all directions as rapidly as possible, so as to cut all parts at once to about the same level, and even square and oblong boxes could thus be cut out of the solid, only needing a little work with a sharp chisel to clean out the corners, which a revolving cutter could not, of course, reach. The practical fault of our drilling machine was that the platform was too confined. There was only space between the drill and the pedestal, or bracket which supported it, for a very small object. We had, however, proved satisfactorily to ourselves that a drill could be used for work of this kind; all that remained was to modify the apparatus, and vary the shapes of the drills, to render the whole more generally efficacious. There was no occasion to provide for a great extent of vertical movement, and with a deeply grooved pulley on the drill-spindle, we could depress it six inches without the cord slipping off, especially when the horizontal part of it, between the driving-pulley and the guide, which turned the cord downwards, was of ample length.

The next point of consideration was the limit to the position of the drill-spindle, which had of necessity thus far only a vertical movement in its bearings, so that no undercutting of the work was possible.

To show the steps by which we advanced, I have given a second drawing at N, by which it will be seen that we pivoted the part which carried the bearings and the drill, so as to be able to place it at an angle in respect of the work, and keeping the latter still upon a horizontal table, we were thus enabled to undercut it at pleasure, and to get under the parts which we desired should stand up clear of the general surface.

The next step was a very important one, and gave us several advantages. It is represented at OP. Here, it will be observed, the bracket which carries the drill is pivoted on a horizontal arm which is slotted, and a bolt goes through the slot into the top of the pillar, which is the main standard of the machine. This gives a radial motion round the pillar, and the drill will describe the arc of a circle, the centre of which is the bolt, and the arm O can by means of the slot be shortened when desired, so as to bring the drill-spindle in close proximity to the pillar P, or extended when the work is of larger area. The latter now has, it will be seen, plenty of room, instead of being confined to a small space as in the first drawing. This radial movement was itself also an accurate guide for drilling round a circle, and was frequently convenient merely for drilling a circle of holes in a plate, as well as for the special purposes of ornamental carving, for which it was devised.

It will, upon consideration, be evident that a mere slotted bar will not necessarily move steadily round a central bolt, but would be apt to slip along it lengthwise. In the slot, therefore, is shown, just above, a sliding piece of brass, which, strictly speaking, ought to be chamfered or cut on each side with a V-shaped groove, and the groove or slot in the arm ought to have been so shaped as to fit into this. Of course we had no means to do this, nor do I think we knew much about such a plan, but we managed something that answered almost as well. We got a piece of solid brass, which we squared

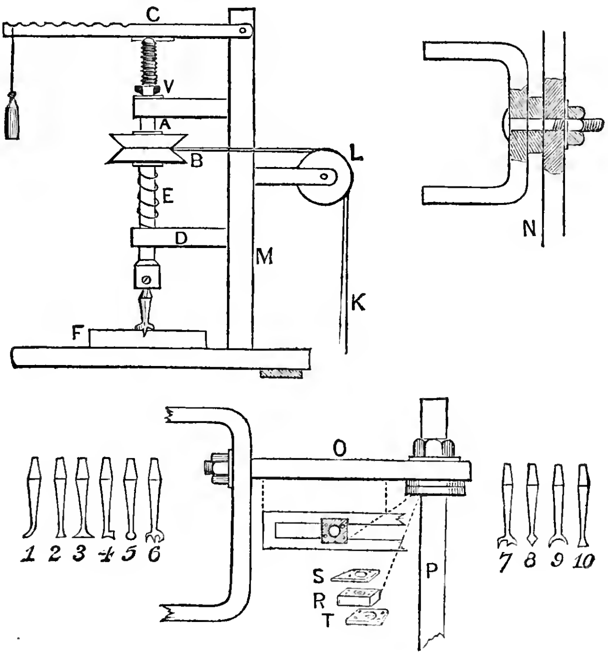

Fig. 24.

up, and drilled in the centre for the main bolt to hold it on the top of the pillar, and which is represented here by R, and we then prepared a top and bottom plate, S and T, to be attached to the block when the latter was in place in the slotted arm. The lower plate was considered a fixture when in place, but the other was fixed by two screws instead of four. The block was a shade less thick than the depth or thickness of the arm, so that when this top plate was screwed tightly down, it fixed the slide securely in any desired part of the slot, but when it was necessary to slide the arm backwards or forwards, the slight loosening of the two screws, which were at opposite angles, sufficed to free it. We put two pins in the other two corners of this plate to save having to manipulate four screws, and the pins were quite sufficient to assist in retaining the plate in its place.

By the time we had made these alterations and additions, it became evident to us that we must not depend on the lathe as the foundation of our carving machine, which, thus modified, was of too large a size to be easily mounted on the lathe-bed. We therefore set to work at a stand, and made our carving apparatus an independent machine altogether, with its own fly-wheel and treadle. We pressed it into service, however, for ordinary drilling purposes, and very handy indeed we found it.

With a perfectly flat, or a plain, round-ended drill at a high speed, we could face over a block of boxwood, and give it a perfectly level surface, simply moving it about by hand all over the platform on which it rested; for this, however, it was necessary to lower the drill to a certain determined distance, which was done by the simple means now to be described, and was another invention of which necessity was the parent.

The upper part of the drill-spindle above the top brass was cut with a rather fine screw thread, and upon this was a nut rounded off somewhat below and case-hardened, and upon the bearing rested a steel collar or washer, also hardened, which was added to protect the brass from wear when the nut rested on it, because it would still be rapidly revolving, and would soon have ground its way into the brass. The spring E, coiled loosely about the spindle, and abutting on the lower brass, held up the drill when it was not pressed down by the lever handle. The nut V was the stop, which could, of course, be easily placed in any position on the spindle, which could no longer descend when it came into contact with the opposing steel washer. This contrivance proved very convenient in drilling ordinary holes to a certain depth.

When the drill-spindle was thrown into an inclined position for undercutting, the pressure of the lever was of course partially removed from the top of it, so that it ceased to act with the same force; but this was easily remedied by hooking on to the end of it a band of India-rubber, or an ordinary coiled spring, such as is used by bell-hangers, and of which it was easy to regulate the tension.

Nos. 1 to 10 of this figure show the drills we made to use with this machine. Nos. 1, 2, 3, are undercutting, and with them this work could be done without turning the spindle out of its vertical position. No. 4 is also an undercutter, but leaves the bottom flat, and makes a rectangular groove below the surface similar to that formed by a grooving-plane; but in combination with the circular movement of the whole drilling-frame upon the upright pillar, it will cut such groove all round the inside of circular work. No. 5 is a simple round-ended drill, useful for roughing down broad surfaces to be afterwards levelled by a flat-ended drill, or for making semicircular grooves and hollows. No. 6 is the ordinary centre-bit, of which several sizes are needed; and No. 7 is a similar tool without the centre-point, and is intended to finish work begun by the ordinary bit. No. 8 is for simple holes or to drill angular grooves; and No. 10, of which there must be two or three sizes, is a narrow tool, sharp on its extreme edge and on the sides, and very slightly wider at the end than it is a little above. Its use is to drill out long narrow grooves, for permitting strips of wood of any desired colour to be inlaid, technically called "stringing." It is evident, that even for such simple work as has been just described, a drilling instrument like the above is a valuable addition to the workshop. Inlaying, especially, is a ready means of ornamenting, at slight cost, the woods which have no special beauty of their own, and modern taste has renewed the old device of running narrow strings or lines of the parti-coloured ornamental woods round the panels of furniture made of plain white pine, giving the articles an elegant and highly-finished appearance, without any considerable addition to the cost of the plainer material. The drill marked 9 allows of no longitudinal traverse, and will not form a continuous beading, as by its rotation it would constantly destroy its own work. It is used for forming a succession of rounded prominences or beads, the drill being lifted after each has been formed, and lowered again upon the adjacent part of the material. A continuous beading can only be cut by a revolving cutter like No. 9 split into two halves lengthwise, and this has to be carried up one side and down the other, so as to cause the two cuts to meet exactly on the centre of the ridge thus formed. There is not much need to use such a tool, however, because a straight beading is more easily made by an ordinary beading-plane, such as carpenters are in the habit of using, and circular-beadings can be cut readily in the lathe with a tool like No. 9 held quite still upon the rest.

As I have had to speak of string-courses of inlaying, concerning which, I daresay, many of my readers have wondered how both strip and groove are cut so neatly, I will here let them into the secret. The groove is made by a tool exactly like the ordinary marking-gauge of the carpenter, but instead of a mere point capable of scratching a line, it has a keen-edged cutter projecting from the stock, which can be made to stand out farther and farther as the groove gets deeper. By this simple tool a groove is cut which is everywhere exactly parallel to the edge of the frame or panel, or part to be inlaid. The narrow strip of veneer is cut with a similar tool, but in this is a mere knife-edge instead of a chisel. In soft wood a similar knife-edged gauge is just run round the work, in order to make a clear cut through the fibres which stand across the path of the intended groove. Without such preparation for the chisel-ended cutter, the latter would not cut with sufficient neatness, however skilfully used, but when it had to pass across the grain of the wood, it would tear up the fibres and completely spoil the surface. Any one can make such cutting-gauges, and they are useful for other purposes as well as stringing and inlaying.

Now it was by no means our intention to limit our machine to such work as that described. We wanted it to assist in absolute carving of any form or object, in addition to mere recessing and drilling. For this purpose, the chief requisite appeared to be the power to move the work itself, or the drill, or both, to a much greater extent than could be done as it then stood. Analysing a drawing of foliage, for instance, it was evident that it consisted of straight lines and curves, but the latter in far the larger proportion. Taking as a sample a vine-leaf, it would, if blocked out, be represented like fig. 25, where I

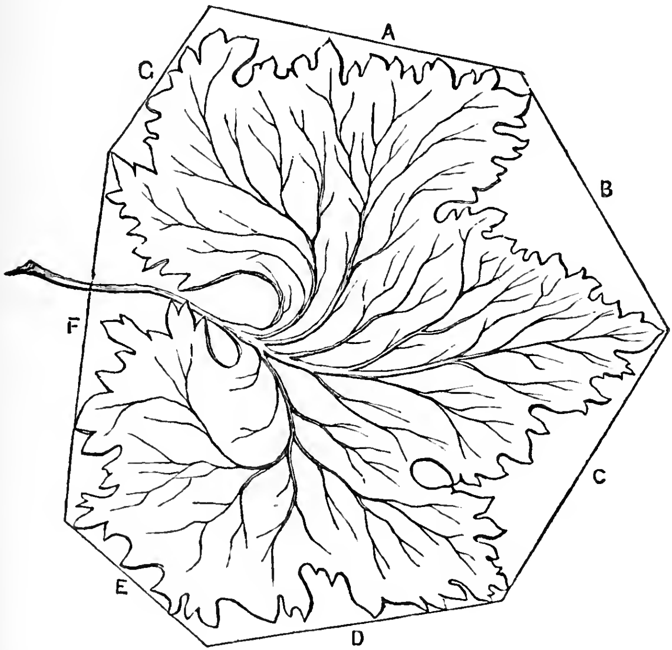

Fig. 25.

have supposed it required to cut such a leaf on the surface of a wooden block, so that it shall stand up in bold relief. The lines ABCDE, drawn round it and enclosing it, show that all outside these may be freely cut away without any fear of injury to the proposed carving. A carver would, in fact, block out his work thus with chisel and mallet, and so would an engraver. A round or flat-ended drill might be therefore made to perform this duty very easily, the block being moved about by hand on a fixed platform, and in this way the outer portion would very quickly be sunk to a sufficient depth below the general level. Still moving the block by hand, the next step would be to drill out the spaces inside the first lines, and to map out the leaf more nearly to shape. This would be done with a smaller drill, probably No. 10 of those shown, which, if keen and working with great speed, would make a well-defined cut, and edge round the leaf very neatly. Then would follow an under-cutting drill to take off the perpendicular surface now existing round the leaf, and level it off below, so that it would stand up more in relief from the block out of which it was cut. For all these operations the work would be kept upon the horizontal platform. If still greater relief were needed, or any part required to be cut clean away from the block, as, for instance, part of the stem or a tendril, or even a portion of the leaf, so as to admit light below it, the block might be turned upon edge and a proper sized and shaped drill passed through under the leaf or stem. But up to this time we have considered the drill as only cutting a level surface wherever it was in action, because it would be pressed down upon the work by the weighty lever or spring, until checked in its descent by the nut, the position of which, as already explained, decides its downward traverse.

In cutting, however, the upper surface of a leaf, it is necessary to be able to deepen at pleasure the cut of the drill so as to cause it to carve out correctly the various depressions, while it must be also able to pass lightly and almost without cutting the higher portions of the object. In Jordan's carving machine, and still more recently in the Medallion machine, the descent of the cutting tool is regulated by a pattern, upon the surface of which a dummy or blunt drill rests, and as this rests or rises and falls it causes the tool at work upon the adjacent block to follow its movements exactly, and the pattern is thus copied with the utmost fidelity.

But ours was not to be a copying machine if we could possibly help it, and consequently no pattern was to be used to guide the path of the drills. We found it necessary to discard the weight or spring altogether, and to depress the lever by hand. This left us but one hand at liberty to move the block about, but with a light one (and we did not attempt heavy work) we did not find this create much difficulty, and we could cut deeply at pleasure; and by easing off the pressure to suit the prominences, we soon found it possible, with merely a round-ended drill, to pass over the surface and follow all the sinuosities of a leaf with very great ease and correctness, and we amused ourselves very extensively and became very expert at this novel occupation.

Beginning with the simpler leaves, we advanced to groups of complicated foliage. Very frequently we could not wholly work these with drills, and had to call in the aid of one or two carving tools to help us, but as far as possible we made the drills do the work. We found, moreover, that, as a general rule, a round-ended drill would accomplish nearly all the details, owing to the fact of there being so few right lines or level surfaces in nature, all objects exhibiting more or less curvature of outline and of surface.

Since our day fretwork has become a fashion with the amateur world, ladies included, but alone there is a sameness about it which soon makes it uninteresting. In fact, it is already not nearly so general as it was a few years ago, for people soon tire of mere tracery of perforated patterns, unless they are obliged to do such work to provide food and clothing, when it no longer becomes an amateur pursuit. To make such work worthy of the labour spent upon it, it should be carved instead of being left flat, and nothing will do this so nicely as revolving drills, because fretwork is very delicate and easily broken, and the pressure of a drill can be made as light as possible. Moreover, with a fine-pointed drill the most delicate lines can be followed, such as those which indicate the elegant venation of leaves. These veins, by the by, it may be as well to state, are not generally grooves on the surface, as they are so often rendered by amateur carvers, but elevated ribs, being, in point of fact, minute branches containing sap, which by their means and by means of the thin membrane connecting them, is exposed to the action of the atmosphere. The leaf membrane is for the most part double, embracing these capillaries of the branches between the two surfaces. The circulation of the sap is in this way very like that of the blood in the human subject, which is brought by the given capillaries to the skin and then returned to the heart to be renovated—the renovating power being the oxygen which it meets with in its passage through the lungs. But I must not stay to dwell here upon this detail of a most interesting subject. The wood-carver secures first of all the main features of the subject in hand. If he has to carve a group of leaves, he will block out, in the first place, the outline of the whole mass, so that he may be able at once with mallet and chisel to cut away all the wood outside it, which he will reduce to a uniform surface or nearly so. He will then see what are the main portions to be similarly mapped out, avoiding for the time all minor details, but always being on his guard to leave plenty of substance, because if the wood is once cut away too much, it is next to impossible to restore it. Of course, before he takes even the first step he will have carefully outlined his work so far as it is possible to do so, but there are lesser details upon the faithful representation of which the beauty of the finished work will depend which have to be cut with no other guide than the eye.

A fast-revolving drill gives a charm to this kind of work, by allowing the details to be traced out as by a pencil, for each line can be followed with great rapidity as well as accuracy; although, if the drill is a fixture, the work itself has to be moved about under it, instead of the tool itself being movable, which would be the more natural and more convenient method. It has often struck the writer (and our inventive readers can work out the idea and make a fortune, as, of course, inventors always do), that a movable drill is not by any means impossible. We all get our hair brushed in these days by revolving brushes, feeling as if hair and scalp were being carried clean away, and the brush, while still at high speed, is moved about in all directions; the driving band being an elastic strap of india-rubber. Our undeveloped notion is a similar apparatus, but driving a drill instead of a brush, which drill is to be carried about the work as required while continuing its rapid rotation. The drill, however, would hardly answer if to be held by the hand alone. It ought to be at the end of a horizontal arm, which arm should have at the end a universal joint to enable it to move with equal facility in all directions. Just work it out, boys, and we don't object to going shares in the profits of the invention.

Revolving cutters are now (1877) quite the order of the day. The wood-planing machine, for instance, is but a roller armed with sharp knives, something like those of a lawn-mower, which are made to revolve at tremendous speed, while the plank is caused to travel underneath it; and wheel-cutting for clockmakers and others is performed by little circular cutters of the form of the spaces between the teeth, which are thus, as it were, sawn out with great truth and rapidity. Twist-drills are channelled in a similar way, and also taps, and reamers, and fluted drills; and the slots in long shafts are drilled out while the tool or the work is made to traverse lengthwise. Revolution and rotation is now the rule, and even human events are often said, not without reason, to revolve in a circle, and thus to repeat themselves periodically.

I dare say our boys may have noticed that on the soft wood-carvings done chiefly in Switzerland, but also in many other districts where fir and similar material is available, a good deal of the ground-work is done with a kind of matted pattern, which has the effect of giving greater relief to the smooth leaves and other sharply cut work. This is not carved, but is merely indented by a punch, on the end of which is generally a star-like pattern, or other simple device, which suffices to give a dead surface easily and quickly produced, and sufficiently effective for the purpose.

There are many devices of this kind used both on wood and metal, and with respect to the latter more especially, the punch, or the roller with a pattern on the outside, which is a perpetual punch, is largely used to produce mouldings, scrolls, and beadings, which give such finish and handsome appearance to the work. The more elevated parts are then generally burnished and lacquered to a condition of great brilliancy, and the recessed parts are dulled by the action of an acid which partially corrodes the surface, thus giving the contrast so necessary in all such works of art. The home of first-class work in metal is, beyond a doubt, Birmingham, but a good deal is also done in London, especially by those who make the various articles used in the decoration of churches.

Before dismissing the subject of our carving-machine, I may add a few words upon carving in the ordinary way, because the work is one of great interest, and boys who are naturally fond of lathes and mechanical apparatus, and accustomed to carpentry, ought by no means to neglect it.

As a lesson, there is one special advantage in this art, which may be regarded as a development of drawing. None will make good workmen but those who are in the habit of observing natural objects with close attention. Again and again the carver must go to nature as his model and copy. There is some special peculiarity in every leaf and tree-stem, and almost in every separate blade of grass—constant variety, and unvariable beauty of outline as well as of surface. An autumn leaf has not the form of the same leaf growing in all the vigour of its summer health and vitality. The beauties of early morning are modified by the action of the mid-day sun, and change their aspect without losing a particle of their loveliness under the softer hues of eventide. There is the distinct beauty of youth and of age, and the well-trained eye of the artist recognises all these, and with brush or chisel, as the case may be, gives permanent expression to the truths which have become impressed on his mind. The boy who tries his hand at carving learns to estimate all the natural beauties of our lovely world at a far higher value than he who cares not to represent them in this way. The one *observes* where the other only *sees*, and to the first nature offers daily fresh delights which the other has not the soul to feel, much less to enjoy. Therefore, if only to open up for themselves new sources of pleasure of the highest kind, I would recommend every boy who can handle gouge and chisel with ordinary skill to turn his attention also to the art of carving. For this, however, he must, in the first place, learn to draw, which, as a mechanical engineer, he will find a matter of necessity; but, then, for the latter purpose, the chief of his work will be done by the aid of mathematical instruments, whereas the delineation of foliage and natural objects will require almost exclusively skill in what is called freehand drawing.

The amount of skill, however, in the latter, which is required in order to commence the work of carving, is not very great, inasmuch as the power of delineating nature by pencil and carving tool will increase with practice, and in learning to carve, the pupil will daily increase his knowledge of drawing.

But what used at one time to be considered drawing is very different to the art as it is now taught.

There is no longer prevalent the *show piece*, done in a great measure by the master, which used to be taken home to show to admiring friends in the school holidays. Some impossible landscape out of perspective, and so unlike any terrestrial features of ordinary landscape, that it would have stood with equal truth for a sketch of somebody's estate in the planet Jupiter. All this style of art has given place to accurate outlines of simple objects, or shaded drawings thoughtfully and truthfully carried out.

Many a lad who in old days used to bring home drawing prizes, and who imagined that he could *paint* as well as draw, could not have accurately delineated a sprig of oak leaves or a simple weed; but now that photography has taught us how to represent our object with fidelity, and now that Ruskin and others have stood up so manfully for truth instead of conventionalism in art, we have arrived at the proper kind of drawing to serve the purpose of the carver. We have learnt to draw simple outlines with the nearest attainable approach to perfect accuracy.

Supposing our young reader to have acquired the power to trace on a block of wood a leaf or a group of leaves, he is in a position to go a step further and carve a likeness of it with the proper tools. These tools have divers names and are sufficiently numerous, but practically they are nearly all of them gouges and chisels. The shanks of them, however, are longer than those ordinarily used by the carpenter or joiner, and they are variously bent to enable them to reach into corners, and to undercut where necessary, and, in short, to do what a straight tool could not.

They are sold in sets, and are not very expensive; and if the student will really set to work with dogged determination to persevere, the result of his labours will amply repay the outlay, which is more than can be said for many of the pursuits in which amateur workmen indulge.

Having, as already described, blocked out the work by cutting to the extreme outline of the whole design, the next step will be to gauge the thickness of it, so as to find out to what depth from the surface any given parts may be lowered, and this depth is to be marked upon the side or edge of the block. Then this part must be blocked out like the first, and lowered as far as necessary, the main tools as yet being a mallet and chisel or a mallet and gouge. But after a while, these will have to be laid aside, and one of the regular carver's tools taken up, and you will learn that these are exceedingly sharp, and must be kept so, and that to have the left hand in such a position as to receive a cut if the right hand should slip, is not exactly the most sensible thing to do. I ought, by the by, to have told you that the work is commonly held by the carver's screw. This is a short bar of iron with a conical pointed screw at one end, which is inserted in the under side of the block of wood to be carved, and it has about three inches of the other end screwed, and a hand-nut fitted to it. This end is put through a hole in the bench, and a washer being slipped on it, the hand-nut is screwed tight. In this way the wood will be very securely held, and both hands will be left at liberty to guide the tool.

The whole further operation will consist of scooping out and cutting the hollowed parts and rounding the convex ones with such of the tools as seem the best suited to the purpose. You will find the gouges all of different curvature, some almost as flat as chisels, others curved to nearly the half circle. Then you will find tools like a folded slip of paper, or the V-tools for cutting screws in soft wood, and others like ordinary chisels, but of varying width. There is no rule as to which is to be used They should all lie before you in a row, so that you see at once the shapes of the cutting edges, and after finishing what you can with any one tool, you should always lay it again in its own place in the row, so as to know in a moment where to put your hand upon it.

The best way is to range them in order of width, which will also be, generally speaking, in the order of curvature; the broader gouges being the least curved, and the narrower ones more so. Order in mechanical work of all kinds is most valuable in saving of time and trouble.

It will have to be remembered always, that, whether in carpentry, turning, or carving, sharp edges must be left, except where the nature of the design absolutely necessitates rounding them off; and wherever this is a necessity, the rounding must be *evidently* done for a set purpose.

Hence the inexpediency of using sand or glass paper to finish work to a smooth surface. All should be clean cut with very keen tools, which will leave such a face as can be produced in no other way.

If a bit of Caen stone is to be had, the young carver can exercise his powers also upon this. It is cut and carved much in the same way as wood, but finished with scrapers of various shapes; it is very soft, easy to cut into any desired shape, and looks exceedingly well when finished. This substance can be turned, and marble also; but even in the case of round pillars it is seldom done in that way, as practical hands will round it perfectly by hand-tools alone.

A visit to any stone-mason's where best work is done, especially a visit to ecclesiastical decorators, such as Cox of London, will prove highly interesting to our young friends if they can obtain admission. There they will see Jordan's carving-machine actually at work, and will see also plenty of skilled workmen carving the most elaborately undercut work by hand alone, both in wood and stone, including the hardest marbles and granite. Such a visit will show him how expeditiously, as well as skilfully, work of this kind is done by those who are well practised in the art, and what exquisite work results from the skilled manipulation of a few simple tools. They will probably go back to their own work with a just sense of its inferiority; and if they are boys of the best metal, they will be roused to greater diligence, and more than ever determine to excel.

I would not give a farthing for a boy who would go back from an inspection of such work to give up his own feeble attempts, and thus confess himself unable to do what hundreds are doing every day. Unless a lad has spirit enough to contend against difficulties, until he compels them to yield to his energies, he can never become a great man, and the most he will do is to crawl through life without doing good to his fellow-creatures, or executing any but the most unimportant work that falls to the lot of mortals. A cat without energy would never catch a mouse, but she ought to have no dinner till she can perform that simple feline duty.

Although in this chapter I have passed from the capabilities of a home-made machine to the capabilities and actual doings of skilled workmen, I may return so far to the actual subject of this volume as to say, that we executed carved work, of probably no great excellence, ourselves, besides what we accomplished with the drilling apparatus. Moreover, we set to work wisely, so far as regards copying from nature. I remember an attempt, not wholly unsuccessful, at a bunch of grapes with a few vine leaves and tendrils, which formed the base of a bracket-shaped stand for a clock, and was duly presented to our father on his birthday. Being carved in oak, we had difficulties to contend with besides those resulting from a very insufficient stock of tools. I am afraid that we also found a difficulty in respect of keeping the grapes long enough to serve as our model until the work was done. Like lads, though, we managed it after a fashion of our own. We began the bunch at one end, and as fast as we roughed out a few of the berries so as to guide our efforts, we forthwith ate them, so that by the time the last grape was cut in wood the bunch had wholly vanished. I have known an artist of maturer years carry out this principle by eating one half of a ripe peach while he painted the other, a representation of the former not being required in the picture upon which he was engaged; so that I may conclude that old boys and young ones have very similar tastes, and are equally disinclined to let good fruit be wasted, so long as it can be made to serve the two-fold purpose of a model of still life and food for life that never is still.

The vine tendril and smaller branches gave us a good deal of trouble, as they were carved in full relief. We first drilled underneath, until we were able to insert the point of a small saw, and thus removed the superfluous material, leaving the stem or tendril standing, for a part of its length, clear of the wood beneath it. We then, partly with a penknife and partly with a rat-tailed file, rounded off the part, and finished it to represent the natural stem. Wherever the latter was so thin as this, we took care to leave it supported here and there, instead of cutting it quite free. This is always done in work of this nature.

Accurate delineation and clean cutting are the characteristics of good work. Glass-paper must be very sparingly used, as it rounds off angles and edges, which ought to be left sharply defined. If the cheap Swiss carvings, now so common, are examined, they will be found very inferior, not so much owing to any neglect of clean cutting, but in having hardly any relief, and in being carelessly worked. Cheaply, because rapidly executed, the material is thin and poor; it is cut out with a small saw into something like leafage, and the upper surface is hollowed variously with a sharp gouge, and a few offhand angular cuts are made to stand for a representation of the leaf veins. So far as they go, they are clever, and far cheaper than they could be made in England; but after all they are deceptions, and not accurate representations of nature, and, except for our younger readers, should not be taken as models worthy of being copied. They come into the same category as fretwork, which is a mere *pattern of nothing*, useful in its way, but not such as the eye of an artist can dwell upon with pleasure. If our readers can visit some old church, or some church of our own times designed by a first-class architect, and carried out by workmen capable of artistic carving, they will at once recognise the beauties of high-class work. They will note how massive it is as a whole, and yet how delicate in detail. They will see also that there is no mere shallow surface-work, but that all is in high relief, and well undercut, and yet that sufficient support is left everywhere to render the work durable, and prevent the lighter portions from being easily broken off. All this is characteristic of work done previous to the Reformation in the time of Henry VIII. and Elizabeth. After that date art degenerated sadly. Instead of being deeply cut, carved decorations were merely superficial, and correct representations of natural objects no longer occupied the attention of the carver. Happily, such work is again dying out, and there is a widely spreading taste for what is well called "high art."

It is not, however, easy to state in so many words in what high art actually consists as bearing specially upon the subject of carving. It is not every one who recognises the difference between what is commonplace and what is really artistic. A simple leaf may bear the first character, and it may equally bear the second; and it is the same with a group of leaves or flowers as of other objects. The Alps are grand, the hills of our own land are beautiful, the hedgebank worthy of the artist's highest skill. The hand of Nature delineates and colours each alike aristically; all alike are lovely, but each has distinctive beauties. A representation of the last may be as high art as a representation of the first, as it is not the *subject* but the manner in which it is treated which characterises the result.

The best way is to seek out as studies what are known and acknowledged to be works of real excellence, especially the carved work to be found in churches of Early English, Decorated, and Early Perpendicular style. Get a taste for work of this kind, and you will not long be content to carve bread-platters and butter-dishes and book-racks.

At the same time there is no harm in working at these lesser objects to get into the way of using carving or turning tools. They are useful if not artistic, and admiring friends will be glad to possess these specimens of your handiwork. But don't stop at such as these, and don't be content to copy other people's work. Work out, if you like, a sheet of fretwork, designed at the small sum of one shilling, and then put the sheet in the fire, and set to work to design from real leafage, which Nature will present you with at all times free gratis, and without even a stamped envelope for reply.

Now, I dare say some of you young fellows are inclined to *cut* all this prosaic stuff of mine. You want to get ahead, and to hear what other mighty works the young engineers accomplished. Well, I don't care much about that. You can turn over, but I hope sometimes you will "hark back," as fox-hunters say, and have another look at the despised pages; for I should not have written them if I were not certain they are full of sound advice.

You know the old saying, Set a thief to catch a thief, or make the biggest poacher in the parish head-keeper, because old evil experiences will help him in his new sphere. Well, we have had our own evil experiences, too, in the carving line. We thought ourselves mighty clever with our fretwork and platters, and such-like artistic sport; but it was like poaching—it would not bear the truthful and pure light of day. We got entranced by seeing some real honest work, and at last we chucked all else aside, and said to ourselves, "We will henceforth aim at the highest, and get as near it as we can." That is all I want you lads to do. Get a noble ambition to excel, and you will not long be found among the slugs and *hoddidods* (as youngsters call the snails), those slimy creeping things that leave their mark, indeed, wherever they go; but it is just that kind of mark which ought to be obliterated as soon as possible. Boys, and men too, leave marks oftentimes of a very similar character, which we need not stay to particularise; but your old friend would fain stir you up to leave behind you such marks of genuine nobleness, reflected in every act of life, in every work of brain or hand, as shall make the world acknowledge that mechanical boys are very high-class human machines indeed, worthy of all kindly help and encouragement.

Chapter XI.

OUR ELECTRICAL AND PNEUMATIC APPARATUS.

IN the year of grace 1877, there are used both electrical bells and pneumatic parcels' delivery apparatus, and also, we believe, pneumatic bells, though not very generally. Now I do not suppose our claim will be allowed if we state that we were the sole originators and inventors of both these bells, although we do not claim the parcels' delivery. But the fact is, we were just like so many of our peculiar race. We talked of the possibility of doing this or that; made a few more or less successful experiments, concluded that the idea would not work out as a practicable marketable invention, and so let it slip, while other more knowing hands made fortunes out of the very same designs. This is just as it should be. An inventor, if he is to reap pecuniary rewards, must prove himself worthy to receive them. He must not get into his head some vague idea that possibly such and such things would be serviceable, and then fancy himself worthy of reward. He must work out each step of his invention until he has ACTUALLY RENDERED it serviceable. Crude ideas are all very well as the seed of great results; but if the sower of them cannot cultivate the tender blade as it springs up, and cannot, from want of necessary skill or knowledge, watch and cherish it till ready for harvest, he has no right to expect a reward. That same seed, we must remember, can be sown by many; and it is a fact that many persons *do* hit upon precisely the same ideas; but whereas one who is of a practical turn of mind will patiently follow it up, and work it out step by step until he reduces it to a marketable commodity, another, with less patience or less energy, will leave it just where he found it, and consequently *he* is not to be called the inventor, although the *idea* occurred to him first. Now it was just so with pneumatic and electric bells. We made both by way of experiment, but as to practical use, we stopped short of it by a very long distance indeed. We argued, that inasmuch as batteries soon cease to give out their pristine power, and as the slightest hole or faulty connection would destroy the air-tight continuity of a tube, neither electric nor pneumatic bells would have a permanent advantage over the usual system, and we therefore never troubled ourselves any more about either. We could ring a bell by either mode, but as to the advantage of any system, we gave the palm to the wire and crank, and considered the other two methods merely as byplay for the lecture-room or study.

But if the history of any great invention is traced from the commencement, it will be found, generally speaking, that what at first was a mere lecture-room experiment, of no apparent practical value, was but the germ of that which, in the hands of the manufacturer, ultimately became of vast benefit to mankind, and of great commercial importance. Photography had just such a beginning. It had been noticed that a solution of nitrate of silver darkened on exposure to the light, and probably the fingers and clothes of our young experimentalists have often borne testimony to this property of the salt in question. Thence it became an amusement to copy leaves and other objects by laying them on a piece of paper saturated with the nitrate, and pressing the two together between two slips of glass, or by clamping them in a frame with a sheet of glass above. Exposed to the sun's rays, those parts of the paper unprotected by the leaf darken, and that immediately under the leaf remains white or nearly so—the leaf allowing the light to pass but slightly through it, and not at all where the midrib and thicker parts exist. A copy was thus obtained which was light upon a dark background, but very soon the whole paper became uniformly black. To prevent this, it was discovered that a solution of hyposulphate of soda would so act on the parts which had not been affected by the light as to prevent any change taking place when light was subsequently admitted, and thus it became possible to fix the photograph and render it far more permanent. Ultimately (for I cannot stay to trace the invention through its various stages) photography became what it is now—one of the most useful and interesting arts of the period.

Look, again, at the toy sold to this day, which was called an æolipile—a small globe with bent, hollow arms, from which the steam of a few drops of water rushing out and striking the opposing air, sent the whole spinning round any number of times in a minute. Or, again, a jet of steam impinging on the vanes of a wheel gave rapid motion to the latter. In each case a mere child's toy was produced, yet herein lay the germ of our gigantic engines of perhaps a thousand horse power.

While I am writing, another invention is *in ovo*, and we can as yet hardly see the ultimate result. Experiments have proved that it is absolutely possible to talk and sing by telegraph. We have in its infancy an instrument called a telephone, by which sounds such as those of speech can be carried to a distance of many miles, and heard so distinctly that the tones of any friend's voice can be recognised. Then, again—though here the infant has reached a stage of larger growth—we have the spectroscope. It is known that a ray of sunlight passing through a prism of glass is divided into a band of variously coloured rays, which are always alike and always in the same order. Some one found that if the spectrum (as the band is called) of burning metals or gases is taken instead of that of the sun, the colours are different and are crossed by dark bands, but that a spectrum of any one burning substance is always the same. From this we now read the various facts of sun and star light, and actually can declare what gases and metals are burning in those furnaces of the far-off luminaries; and other grand facts of nature will no doubt yield up their well-kept secrets to the persevering inquiries of the scientific world. All these and similar discoveries, which will soon become so familiar to us all that we shall not regard them as anything specially marvellous, have sprung from very small beginnings; and although scientific men are often set down by the ignorant as mere experimentalists, wasting time over useless if not absolutely childish pursuits, the world is indebted to them for the advance made year by year in our civilisation and commercial prosperity. The usual course is this: The man of science discovers a fact not hitherto known—some peculiar law of nature or of some substance in the natural world. He makes experiments, testing his discovery under various conditions, and gradually is able with confidence and decision to declare the laws which govern it, and probably also to suggest some one or more possible applications of it. Then comes the practical manufacturer with his own peculiar knowledge, and adapts the facts already ascertained to the trade processes with which he is familiar; while in all probability other manufacturers recognise the possibility of the same invention becoming serviceable to them also; and what at first appeared likely to profit one class only, frequently turns out to be of universal value.

But our boys will be asking who gets the profit? That depends very much upon circumstances. The scientist is unfortunately not always nor generally a business man, and he is obliged, as above stated, to content himself with the bare facts of his discovery. Very often its applications, or possible adaptations, do not strike him at all. He is taken up with the gradual development of new facts connected with it which arise as he carries out his experiments. He has not the time nor the peculiar frame of mind necessary to recognise the commercial value of what he has discovered, and though he may gain honour as the inventor or discoverer, that honour does not generally carry with it much in the way of profit. It is an honour as empty probably as his own purse. The manufacturer reaps the pecuniary reward—sometimes a very substantial one indeed; but in so doing he in turn opens up in all probability new sources of profit for others owing to the close connection existing between commercial industries.

You see, therefore, boys, that it is as well to cultivate business habits as to carry on experiments in the department you may have selected as your own line of life; and at any rate, if you should make a discovery or hit upon a new invention, get some *real* friend of extensive knowledge in commercial matters to give you the benefit of his advice; but take care he is a real trustworthy friend before you take him into confidence. In no case will you get all the profits, and by judicious management you may perhaps secure your proper share.

As regards our electric and pneumatic apparatus, we got *no* profits, simply, as I have explained already, because we did not carry our experiments far enough to become of practical use to any one. But how far we actually went I will now explain.

We will begin with the electrical department; and as I don't know how far my readers are acquainted with the mysteries of batteries, and with the nature, so far as known, of what we call electricity, it will be necessary to say a few words about it by way of introduction.

What electricity is we do not know. It has a great deal in common with light and heat, and it has been supposed to be so far identical with these that they are in reality all the same under different conditions. They are, in fact, in a certain degree interchangeable, each producing the other. But after all the theories which have in turn been advanced and rejected about the precise nature of these mysterious powers, we have practically to deal with their *effects*, and, consequently, it is to these that our attention as practical people is chiefly directed.

There are several modes in which we can produce electrical effects. If we heat a sheet of coarse brown paper by the fire, and rub it sharply with a piece of dry flannel or the coat-sleeve, we shall apparently bring to a state of tension its inherent electricity; and if we hold it in one hand, and apply to the surface the knuckles of the other, a sharp snap will be heard, and a spark will pass from the paper to the hand, after which the former will renew its normal condition, or, at any rate, will have but slight electrical properties, which will soon cease altogether to exhibit themselves.

The same sheet may be excited again an indefinite number of times with the same result; and when thus excited, it will attract to itself dust or feathers, or other light substances near it, which it will retain, and after a while let drop and pick up again; or, if held above the head, the hair will be similarly attracted, and stand literally on end, as it is supposed to do in cases of fright; but whether it does so or not I cannot say, because I never was sufficiently terrified to put the matter to the proof.

A glass rod dried thoroughly, and rubbed with a silk handkerchief, will also pick up light substances, and behave itself similarly to the sheet of paper; but any such substance picked up by the one will be repelled by the other if held near, showing that though electricity is excited in each, it is of a different nature. This is generally called positive and negative electricity, but it might be called, I think, electricity of two poles, like magnetism, of which there is, at the ends of any magnetised bar, exactly a similar condition of the force, one end of the bar repelling, the other attracting, similar poles held near it. The north end of such a bar attracts the south, and repels the north end of a similar bar, and positively electrified substances repel positively, and attract negatively, electrified ones. There is no knowing why the electrical condition of a substance should be thus brought into a state of tension by friction, so as to render its existence visible; but there arises again here a strong suspicion of its identity with heat, which we all know to be similarly excited; and when we rub our hands together or strike them to produce warmth in winter, it is quite possible that, in the production of this warmth, we also produce a difference in their electrical condition. It may be said, perhaps, that unless we can arrive at some certainty, it is of little use to theorise on this matter at all, as it is quite as likely that our theory, whatever it may be, will ultimately prove false; but it is impossible to go on with the study of any science without theory, which arises almost of necessity as the result of experiment.

Suppose you had come into possession of a pair of balanced magnetic needles, such as are used in ships' compasses, and your experiments had shown you that both of them exercised an attractive, and yet both a repulsive force, as you would very soon discover. You would, of necessity, begin to build up the theory of magnetism under two conditions. You would reason thus: "Here is a peculiar force or power existing alike in both these needles, which seem to divide in the middle of them, for below a central line each attracts the same end of a similar needle, and above that line it repels that end and attracts the other." And you would be on the road to discover the poles of magnetic bars or needles; you would see that the north pole of one attracts the south pole of another, and repels the north, and so in a similar way with the opposite ends; and the further you carried on your experiments, the more perfectly would you find the theory establishing itself in your minds, of a positive and negative pole; for you would find that it is impossible to produce the one without at the same time producing the other.

And as soon as you had thus laid the ground-work of a theory of magnetism, you would find yourself in a far better position to continue your investigations and to carry on your subsequent experiments. For us, of course, it was only necessary to follow the beaten track already laid down by men of science, original research not being much in the way of youngsters like ourselves. We therefore read sufficient only of our subject to make us familiar with the more generally recognised laws of electricity and magnetism, and then proceeded at once to put our knowledge to the test of experiment. We found that of the two means employed to generate electricity, chemical action was most used, as being easier in many respects to manage than friction. The first bells, however, ever made were constructed in connection with the ordinary frictional electrical machine, with its glass plate or cylinder and amalgamated silk rubber.

The chief reason for abandoning frictional electricity as a source of power is the uncertainty of its action. The old cylinder or plate machine had generally to be coaxed and coddled before it would act at all. It was necessary to rub it dry before the fire, and leave it to become warm; and even a little adherent dust would often suffice to weaken or wholly prevent its action. On a fine sharp frosty day the machine exhibited its full vigour. On a damp foggy day, when, of course, some friend specially called to see a few experiments, these would utterly fail.

This sort of waywardness would never do for transmitting telegraphic signals, or ringing-bells, or driving clocks; and if no more satisfactory source of electricity had been discovered, we should never have arrived at our present perfection in such matters. Moreover, although frictional electricity would send forth a continuous stream of sparks, these were not exactly what was required. They might be compared to the fire of a file of musketry, being a succession of little explosions, which, however, could be, as it were, bottled up, and let off with a big bang all at once.

Passing by the old story of Galvani and his wretched frog, there is no doubt that that vivisectionist experimenter was the first to observe the electrical effects excited by chemical action, or, as it was then supposed, by the contact of metals of different degrees of oxidability. It was eventually shown that mere contact did not suffice, but that it was necessary for the metals to be acted on by some fluid which could affect their composition and change their chemical condition, generally by the process of dissolution. It was also found to be important that the solvent used should be such as would act on one metal more vigorously than on the other; and a common combination was a rod of zinc and one of copper (or plates of these metals), acted on by a dilute solution of sulphuric acid and water.

If a strip of each of these metals are placed in a tumbler opposite to each other, but not in contact, and the tumbler be half filled with the above solution, or with strong salt and water, very little action will be apparent at the surface of either metal, and none at all if the zinc is pure, or if it is amalgamated with mercury, by rubbing some over it while wet with the acid with a piece of cork or a bit of cotton-wool. (Don't use the fingers, or you may find you have become a patient for the family doctor by reason of mercurial poisoning.) But if now the upper ends of the metals are connected by a copper-wire, or caused to touch each other directly, a quantity of bubbles will rise on the surface of the zinc, and a current of electricity will pass, which will cease as soon as contact between the metals is broken.

But I am sure my boys will ask, "How are we to know whether or not a current is passing at any given time?" In a very simple way. You all know what a mariner's compass is, viz., a steel needle magnetised and suspended to turn freely upon a point, and this needle, if left to itself, will stand north and south. The ends are called poles, so that we have a north pole and a south pole. All magnetised bars have these two poles, and if you bend them like a horse-shoe, thus bringing both ends almost together, the poles will remain unaltered. You can make such a needle very easily by rubbing with a magnet a common sewing-needle, and passing it through a bit of cork to form a centre. From this you can either suspend it by a thread, so as to leave it free to turn, or you can float it in water; and in each case you will find it arrange itself so as to stand north and south. So much for our compass needle.

Now if you set up your simple battery of zinc and copper, and connect the two metals with a wire reaching across from one to the other, and place this so that the wire lies north and south, you are ready to test the passage of the current.

The moment you bring your suspended needle over or under the wire, round it goes, and stands east and west, or at right angles to its former position. If the current, however, is very weak, it may not quite reach this position, but it will turn some distance towards it. If you hold the needle above the wire, it will turn in one direction to take up its new position; and if you hold it underneath, it will turn the other way, so that you can also prove in which direction the current is passing, as well as gauge its strength.

A little consideration will show you how to intensify the effect of the current. If you coil the wire so as to form a loop (but you must not let the wire touch itself), and place the needle in the loop thus formed, the upper wire will act as stated, and the lower also, so that the needle is deflected with twofold power.

This power can also be still increased to a very much greater extent by using what is called insulated wire, *i.e.*, wire covered with silk, cotton, gutta-percha, or other non-conducting substance, and coiling it round and round a great many times, so that instead of the current passing round the needle once only, it may do so several times.

If the wire is not thus covered, and the coils touch each other, they will act only as a single coil, because the current will pass freely from one coil to another; but with insulated wire it cannot escape thus laterally, but is compelled to traverse the whole length, whether it be an inch or a thousand miles.

It will be easily conceived that the necessity of always arranging the battery-wire north and south would be practically a drawback to its use, and this can be avoided by using an astatic needle—*i.e.*, one which, having a north and south pole, will nevertheless stand in any position in which it is placed indifferently.

This needle is simply a compound arrangement—a combination of a pair of equally magnetised needles attached to a common centre, to make which the simplest way is to magnetise two sewing-needles, so that one may have the north pole at the eye, the other at the point, and then to stick both in the same bit of cork, one above the other, the north pole of one just above the south pole of the other. If they are pretty equal in magnetic power, it is plain that the tendency of one to stand with the eye to the north is just counteracted by the other, which would fain take the opposite position, and thus the effect of the earth's magnetism is annihilated or balanced, which is practically the same thing in this case. Thus, if we make an astatic needle, and place it so that the lower one is inside the coil and the other above it, we get a powerful combination, which, as it were, multiplies the effects of the current as many times as there are coils, and an instrument is made by which a very minute quantity of electricity passing along the wire is instantaneously detected. The instrument is called a galvanometer or galvanic multiplier.

For ringing a bell, which requires a considerable amount of the mechanical power, the deflection of a needle by the electric current will not suffice, but this is the ordinary needle-telegraph that is seen at railway stations, post-offices, and other places. We shall, therefore, pass on to another effect of the current, but we thought it as well to explain first of all how we could detect such a current in its passage along a wire where no spark or sign is visible to tell of its existence.

If a current of electricity is sent from a battery through a wire insulated in the manner already described, and coiled several times round a bar of soft iron, the iron will become a temporary magnet, and will continue to exhibit all the peculiarities of such—a north and south pole, for instance, and the power to attract iron and steel—as long as the current continues to flow; but the moment it is interrupted the magnetism of the bar will cease.

It may be mentioned also here, that a coil of wire through which such current is passing becomes itself magnetic, and if free to do so, it will place itself north and south—or in the magnetic meridian, as it is called—just the same as a magnetised needle.

This property of the current was rapidly turned to several practical uses, and bell-ringing at a distance was one of the first. It was also thought to be a favourable power for use in driving machinery or actuating a clock, which would continue to go as long as the strength of the battery remained unimpaired. The bell would ring, however, in a different manner—viz., by an interrupted current, as will be presently explained, the hammer striking as often as such interruption took place.

It must not be supposed that a slip of zinc and one of copper in a tumbler would suffice for any practical purpose, although the existence of a tolerably strong current is readily seen. Indeed, if, instead of a narrow strip of metal, sheets of some size are used, and the wire connecting them is small, the latter will be actually heated white hot or fused as the current passes through it. The quantity of electricity thus generated is indeed enormous, but action soon grows weaker, as the dissolved zinc interferes with the passage of the current; and not only so, but gradually becomes deposited on the copper, thus diminishing the exposed surfaces of the metals. The result is that the action of this kind of battery soon ceases altogether. Before passing, nevertheless, from this class to the next, we must state that the power of such a combination was vastly increased by multiplying the elements of which it is made—*i.e.*, the zinc and copper plates. Suppose a row or a circle of tumblers, in each of which is a plate of zinc and one of copper, but the zinc of one coupled to the copper of the next, and not to its own, by a copper wire soldered to the metals. The last of the series would be a solitary zinc on the one side, and an equally solitary copper at the other. To each of these a wire is soldered, and any object or arrangement intended to be affected by the current is placed between these two wires so as to complete the connection, or the wires may be themselves brought into contact, when a current will pass. This current is not great in quantity unless large plates are used, but it is of great intensity, producing effects which a single pair of large plates, equal in size to the whole set thus arranged, will not supply. It is not easy to explain quantity and intensity, but the best example of it in another substance is steam. In the boiler, it is in a state of high tension or intensity, but the quantity is no more than if we release it, when it will form a large cloud, but though the same amount of steam is there, it floats idly above us. It is quantity which in the boiler becomes intensity. The heating power of a current is always seen best when a large pair of plates are used, or where the electric current is large in quantity and the wire so small that it cannot conduct it fast enough, the heat arising, it is supposed, from resistance, as the smaller wire will fuse, while a large bar as the conducting medium will be scarcely warmed.

Electricity in quantity, however, without intensity, will not manifest other serviceable peculiarities. It will not, for instance, produce chemical decomposition, such as dissolving water into its constituent gases, oxygen and hydrogen, or effect chemical changes in other substances, unless the different elements in those substances are but freely held together in their natural state. We shall, however, probably recur again to this action of the current, when we speak, as we propose to do, of electrotyping and electroplating. We must now return from our wanderings to the bell, the construction of which was and is very simple. The battery, however, being of necessity one needing great permanency of action, we must speak of it first, as the simple pair of plates would probably cease to act in an hour or less.

Professor Daniell was the first to inquire into the causes of decreasing action in a galvanic battery, and to devise a remedy. He first of all directed his attention to the escape of hydrogen gas, which rose in thousands of bubbles as the acid acted upon the zinc and dissolved it, carrying off with it in its ascent a good deal of electricity, but a great quantity of this gas adhered also in bubbles to the surface of the copper, and the zinc being also dissolved and forming an oxide, the solution became saturated and weakened, and by and by the same oxide of zinc depositing upon the surface of the copper, action wholly ceased. The solution of the difficulty lay in preventing, if possible, the evolution of hydrogen and formation of the zinc oxide, or, at any rate, in preventing its deposition upon the copper plate. This was accomplished by enclosing the zinc in a porous vessel with its acid solution, and thus keeping it apart from the copper. The porous diaphragm may be of brown paper, sailcloth, pipeclay, or plaster of Paris, which last is generally used, or of ordinary china, in the state called biscuit, *i.e.*, before it has been' glazed and fully baked. This inner vessel (for it is generally arranged so as to stand inside the others) may be filled with the sulphuric acid solution, or with salt and water, muriate of ammonia, and possibly some other solutions; but these do not come into contact with the copper, which is surrounded with a solution of sulphate of that metal, constantly replenished and kept up to a state of saturation by crystals of the salt resting on a shelf just level with the surface of the liquid. How then does this become weakened so as to need such fresh supplies of the salt? By the action of the rising hydrogen, which combines with the oxygen of the zinc oxide, and now reduces the copper and deposits it in a metallic state on the surface of the copper plate, which is thus constantly renewed. If sulphuric acid is used as the exciting solution, the surface of the zinc is amalgamated as stated above, and then no local action takes place until the two metals are united by the connecting wire or band, and then the zinc is only dissolved very slowly indeed, while the *electric* action is steady and powerful. The copper deposit is of a beautiful red colour and is *pure* copper. Thus it is evident that the action of this battery, unlike that of the two elements with a single solution, may be kept up for a very long time without any important diminution of power, the disturbing causes which render the simpler battery rapidly weaker being wholly removed. It is therefore called Daniell's constant battery, and was the one which we always used, because it was easily and cheaply made, and also very convenient.

Generally speaking, a Daniell cell consists of a solid rod of zinc, standing in a porous plaster tube—the rod being about half to three-quarter inch diameter, and the

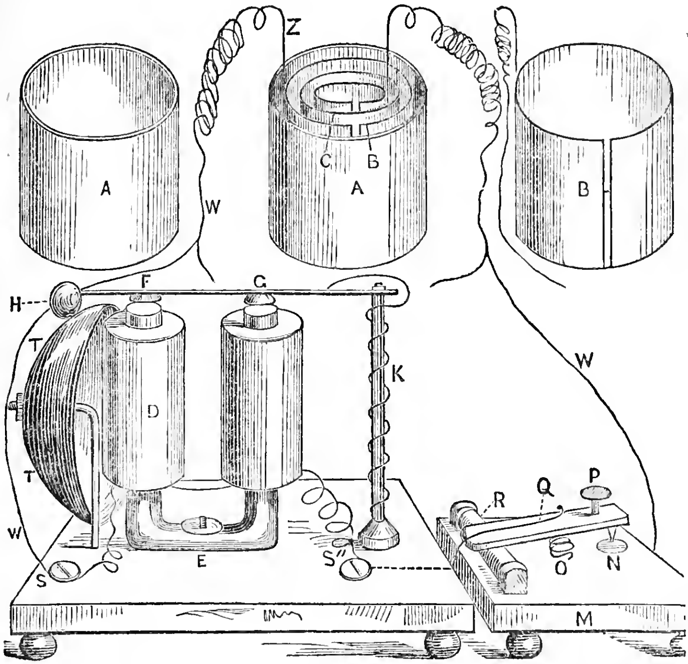

Fig. 26.—Daniell's Galvanic Bell.

porous tube an inch and a half: its size is of no great importance. This stands in a cylindrical copper vessel the same height as the porous tube and zinc rod, this outer vessel forming the copper element of the battery, and being about the size of a common one pound gallipot. Inside is generally a shelf of perforated copper, and this, which is circular, forms also a support to the inner porous tube containing the zinc rod. Keeping of course the principle of this battery, we made ours as follows, which is an equally efficient plan, and more easily constructed.

Fig. 26, A is a common earthenware jam-pot, calculated to hold a pint of solution. Inside it is a plate of copper, B, about as thick as a sheet of ordinary pasteboard, the substance being of no importance, because all action takes place upon the surface of the plate only. Too thin a plate is, however, inconvenient, because it does not give a good support to the conducting wire which is soldered to it, but if it *is* very thin, it will be as well to let the wire go quite down it to the bottom, and to solder the whole length, which will stiffen it. This plate is of such a size that, when bent round into a cylindrical form, it just fits the pot, resting close like a lining inside it. It need not be soldered, because the pot in which it is placed holds the solution. The porous cell C we made thus: We took a sheet of stiff but not very thick brown paper, and coiled it to form a cylinder, which we joined with stiff gum-water up the side. When dry, we cut out a round piece of wood in the lathe to form the bottom, which we put in place, and secured with two or three small pegs of hard wood. This cell was about half the diameter of the outer one. To stiffen and make it of a more permanent character, we now painted it all over on the outside with plaster of Paris of the consistence of thick cream, which we laid on with a hog's-hair flat brush, purposely leaving this coat in a very rough state. We also plastered the bottom to render the cell water-tight. When dry, which it soon became, we repeated the process with a stiffer coat, laid on in the same way, and also poured a little of it inside so as to make a more solid bottom. When this was dry, we rubbed it down to reduce it to a smooth surface for the sake of appearance, just as we do many things equally useless, for it would have answered as well in the rough state. We now had a very fair cell, very porous, and sufficiently stiff if carefully used to last a long time, but it was not much thicker even with a third finishing coat than stout cardboard. We finished it by drying in the oven.

Our zincs we first thought of casting, but we subsequently determined to use sheet-metal instead, as easily procurable with a nice smooth surface; and we therefore cut it out and amalgamated it on both sides, and then coiled it into the form of a cylinder, as we had previously done with the copper, so as to line, but not press, the porous cell. The amalgamation of the inside of this zinc cylinder was solely to protect it against undue local action, for we had already learned that it was only the outer face which was opposed to the inner face of the copper which had any effect in producing the electric current. Hence, also, the cast rods are as effective as the coiled zinc plate, and being harder in practice, owing to greater steadiness caused by their weight, are generally used by the makers of electrical apparatus. A copper wire was soldered to the zinc, and to give elasticity and freedom in arranging cells side by side, or connecting them with other apparatus, this wire was coiled round a rod a few times to convert it into a helix, the rod being afterwards removed. By this means it was an easy matter to lengthen or shorten these connecting wires as might be necessary, and there was less danger of upsetting pot and all in adjusting them, as not unfrequently happens when there is no such elasticity provided. A single cell thus constructed instantly raised to a white heat a few inches of thin platinum wire connected to the ends of the copper wires by being twisted round each, and a bar of soft iron three or four inches long, surrounded by a few coils of covered copper wire (the size of bell-wire), became strongly magnetic when the ends of the coil were connected to those of the battery. We made, however, a set of four of these half-pint cells, and with these we were able not only to sound a bell at any required distance, but to carry on an extensive course of experiments, including the working of a telegraph and simple clock, which had but one fault—it did not keep correct time!

Since the days of those early experiments, a great many forms of battery have been invented and put to the proof, but Daniell's, in a modified form, still bears the palm as an efficient and easily-constructed arrangement, calculated to bear the wear and tear of rough usage, and of which the copper element is saleable at any time at a good price as old metal. It is, in fact, from the very nature of the arrangement, absolutely improved and thickened by use, and it is only the zinc element and the porous cell which require renewal.

Of course, we spoilt our clothes, and made the usual messes with our acid solutions, but all was carried on in our workshop, where no carpets or curtains existed, so that we did no great harm. Here, then, at a small cost, we possessed a battery quite equal to our need, and although we subsequently took a turn at electrical work with other forms of battery by way of experiment, our bell was connected with this simple arrangement of Daniell's, and I shall now describe it in detail before proceeding to speak of other apparatus of a similar nature.

First, there is a mahogany board or base, and upon it is fixed by a screw the horse-shoe electro-magnet D. This is a bar of soft iron, round which is wound in two coils a quantity of insulated copper wire covered with silk or sealing-wax, varnished for neatness, and to preserve it from injury. The wire, it must be understood, is wound first on one leg or side of the horse-shoe, and then carried across and wound in the same direction round the other. The ends are left out and carried to SS, two brass screws. FG is a piece of watch-spring, on which at FG two small lumps of steel are soldered, or one lump extending over both poles of the magnet. This is called the keeper. The spring is fixed on the top of an upright rod of brass or wood, K, screwed firmly to the stand. T is the bell, an old clock-bell, fixed as shown, and H is the hammer, which does not touch it quite even when the keeper is drawn down; but when this happens, the sudden jerk causes the hammer to strike, owing to its being on the end of a spring. If, however, the keeper is gently lowered with the finger till it rests on the poles of the magnet, the hammer is about one-sixteenth of an inch off the bell. This is necessary, or the sound would not be a clear sharp sound, but a dull jarring one; and in all cases hammers to strike bells are so poised as to spring back a little after the stroke is made, and not to rest upon the bell. The hammers of a pianoforte also leave the wire the instant the note is struck.

We have explained that the electro-magnet has no attractive power unless a current of electricity is passing round it. In this case, the current is produced by the battery above it; but, as sketched, no current will pass, because there is no connection between the zinc and copper or positive and negative poles of the battery. No action is therefore going on; the soft iron is not magnetic, and the bell does not ring.

Now look at the apparatus marked M. It is, like the other, a stout board of mahogany standing on four knobs or legs, which are of no special importance. R is a roller of wood turning on pivots at each end; P, which is fixed to it, is a flat plate of tolerably stout brass, held up a little above the horizontal position by a short coiled spring, O. Q is another but lighter spring just pressing on P, so as to be in perfect contact with it, whether it is in the position here shown or pressed down, but it is not strong enough to resist the action of the spring, O. N is a cup-shaped hollow in the mahogany board, into which projects the end of the wire W, inserted from underneath, and this hollow is filled with mercury—with which also the point of the wire is amalgamated, thus ensuring perfect contact. A pointed brass wire is soldered into the part P, so as to dip into the mercury when P is pressed down by placing the finger on the flat-headed screw seen above it, which is not absolutely necessary, as the finger might be laid directly upon P, but it gives a finish to the apparatus. A wire from S is in metallic contact with the spring Q. Let the pointed wire now be depressed into the mercury. The connection is at once established between the two poles of the battery, and is also made to pass round the coils which surround the magnet. Starting from Z, the zinc end of the battery, it will pass by N to the mercury, thence by P and the spring R to S, where it meets the end of the coil. Passing round this it goes to S at the left hand of the apparatus, and thence to the copper element of the battery, completing the circuit. But the moment communication is thus established, FG is attracted and goes down with a jerk, causing H to strike the bell very sharply; for so instantaneous is the action, that no measurable time exists between the depression of P and the stroke of the bell, which can be repeated as often as desired by depressing P and allowing it to rise again, and thus a succession of strokes can be made on the bell at pleasure.

In order to bring all the apparatus into one picture, M is represented close to the other piece of apparatus, but it is not so in reality. The battery A may be, for instance, with the bell and its adjuncts, in the kitchen, or the battery may be in the cellar, and the bell in the kitchen, with a wire from one to the other. But M must be in the room from which the bell is to be rung—*i.e.*, in the parlour or sitting-room, as the wire connecting S and Q may be of any desired length, and also that from the battery to N. Miles and yards are all one in making electrical connections; although, of course, with very long wires more care is necessary to prevent the damp atmosphere and other causes from affecting the completeness of the circuit. When the apparatus is required within the house only, insulated wire alone should be used, as it is not very expensive, and saves battery power; but for longer circuits, where it would be too costly, more battery power is needed to make up for waste of electricity by its escape into the atmosphere, or from other causes which affect it. In damp weather electrical apparatus never acts so well as in dry weather.

It is evident that every time the handle of P is depressed *one* stroke will be given, so that to ring a good peal, P must be depressed rapidly a great many times. But this need not be done by making an alteration in the arrangement. Let the wire from the right-hand coil be brought to the base of the pillar K, and soldered to it. As the pillar is metal, and also the horizontal spring, both these will become parts of the circuit along which the current will pass. The wire twisted round the pillar being insulated (covered with cotton, or sealing-wax, or gutta-percha), will not take up any part of the current which passes along K, and the end of it is attached to Q. Of course, as explained, the length of this wire is of no importance. The end above K is bent over and rests on the spring G; and to make more certain the metallic contact, both should be amalgamated, but they will do without. The dotted wire at S leading to Q is of course not in this case used, and there must be no connection made here.

Let P now be depressed as before. The current will leave the zinc as before, pass to the mercury cup, thence along P and Q, where now there is attached the end of the coiled wire K; up this coil to the horizontal spring, thence down the brass-pillar to the magnet, and back to the battery. The moment this connection is made, down goes the keeper, and the bell is struck; but no sooner does this occur than connection is broken, because the curved end of the wire K no longer touches the spring, and as the magnetism of DD instantly ceases, up flies the keeper. But then connection is immediately made again by the horizontal spring touching the bent wire, and another stroke is given on the bell, and this goes on incessantly as long as the pressure of the finger on P continues, the spring with the hammer oscillating at a tremendous pace, and making such a row on the bell as would awaken the Seven Sleepers. The board E may be screwed to a wall, and the whole arrangement may be considerably modified. In the drawing, DD should be nearer K, so that there may be a longer bit of the spring between J and H, to give more elasticity to the hammer, or the latter may miss striking if the current should get weak.

If the plan here given is to be carried out exactly for practical use in a house, the board M and its fittings may be let into the wall, and the knob on P need be shown, which may be of china or ivory. A still easier apparatus to make would be arranged by forming P of a bit of tolerably stiff clock-spring, fixed into the board at one end, and so bent as to stand up a little above it at the other end. It would not then need the supplementary springs Q and O, nor the roller and its bearings. For actual use it would be much better thus modified.

Possibly some of our young readers may wish to repeat the above experiment, and fit up one or more electric bells or other electric apparatus themselves; and so, before speaking of our pneumatic bell, we will add a little to the information already given.

There are in these electrical machines several connections to be made, to *complete the current* as it is called. Now it is absolutely essential in all cases that the metallic contact should be perfect. A little dust getting in at the places in question would be fatal, and rust and other causes sadly interfere with the passage of the current from one part to another. Whenever, then, you find such apparatus fail to work, always suspect the connections, for here you will generally discover the cause of failure. Copper wire and brass are more generally used than iron or steel, and these should always be wetted with sulphuric acid, and have a little mercury rubbed on to amalgamate parts which are to come into contact.

Where a steel spring has to be used, it is a common plan to solder a bit of platinum foil to any part which is to form a point of contact of this nature, because this metal is not liable to rust, and is a good conductor of electricity. When copper wire covered with silk or cotton is used to make a coil like DD, it should be carefully examined to see that it is really well covered, because otherwise the current will pass at the uncovered part to the iron, and be of no avail for the intended purpose.

You can make a magnet with plain copper wire if you are on your guard in this respect, thus: Wind a bit of silk or worsted or a strip of flannel or any non-conductor round your iron bar so as to cover it; or turn a bit of wood like a cotton reel, with very broad flanges at the ends, and bore it till it will slip over the iron, making one for each limb, or wrap paper or card round it. The big reels will be the best, because they will prevent the coils from slipping. Now coil the copper wire round, leaving the coils sufficiently open to preclude all chance of their accidentally touching each other at any point. Wrap this round, as before, with a bit of silk or flannel, and then wind the coil back over the first; and so on till you have added as many coils one over another as you wish to have. Wrap the last with a bit of green silk, or varnish it with red sealing-wax—varnish made by dissolving the wax in spirit of wine—and you will have a perfectly efficient electro-magnet, but it will have cost a little more trouble to make. In every case, even when covered copper wire is used, it is better not to wrap it directly on the iron, but to use what I have called the big cotton reels, or a covering of card. The cotton reels, however, having broad ends, allow you to coil the wire very neatly on them, and when the last coil is on, and the whole wrapped round, and the wood varnished, the apparatus will present the neat and workmanlike appearance so attractive in apparatus bought at the philosophical instrument maker's.

Covered wire is not expensive by any means, and can be bought at scores of places in London and often in large towns; and there is no better exercise for mind and hand than to make all the apparatus needed, instead of buying it. Merely twisting the ends of wires together, after taking off the cotton or silk, will form a metallic connection between them, but it is better, in addition, to solder them wherever possible.

I have said nothing yet of the cup-like hollow N filled with mercury. This is an old and excellent way of forming a connection. If the wires dipping into the mercury are themselves coated with that metal, nothing can be more perfect than the contact thus attainable. The experimenter should, however, be cautioned that the mercury will effectually spoil any gold with which it comes into contact, because it forms with it a very brittle amalgam. Rings and chains and gold watches should never be worn, therefore, when mercury is to be used for any purpose. In my younger days I had no such difficulties to contend against, because I had no gold at any time; but boys are somewhat changed to what they were—(the more the pity), and get hold of cheap jewellery and cheaper cigars, and other like abominations, which take away the old boyish energy and manliness, and substitute a priggishness and unnatural precociousness which is detestable. In old days, boys had no ambition to be anything else, and were rather inclined to regret the fact that marbles, tops, and other treasures must soon be laid aside for the more serious pursuits of real life. But nowadays boys wish to be thought men, and fancy that by poking nasty cigars and pipes into their lips, dangling a watch-chain, and wearing rings and shirt-studs and pins, they look like their elders. Poor fellows! how they must inwardly lament the absence of whiskers and the deep voice of manhood, which they vainly strive to imitate. This book will be useless to young prigs like these; but as long as we have a few real hearty English boys left, there will be some worthy of our best exertions in writing for their benefit, and it will give us pleasure to help them in all possible ways to amuse themselves profitably during leisure hours and during their much-valued holidays. A very extraordinary circumstance connected with electro-magnets must be mentioned here, as we shall have to refer to it again by and by. Suppose the ends of the coil wrapped round the magnet to be connected with the battery, by any means that will cause the current to flow and to stop alternately at will (as, for instance, the method adopted in the last case for producing a rapid succession of strokes upon the bell). Now suppose that a very fine covered wire is wrapped round over the first coil — a great length is necessary compared with that of the first or primary coil—and the ends of the secondary coil are connected with a galvanometer or compass needle as already described, so as to enable us to detect the passage of a current by electricity if such should occur. If the ends of the first wire are connected immediately with the battery by being attached to its plates or to its terminal wires, and the ends of the secondary fine coil are attached to the galvanometer, the needle remains steady; but if contact is broken for an instant between the first coil and the battery, the needle is instantly deflected, but only for a moment; and if the contact is then made again, it is deflected momentarily in the opposite direction, thus proving a current of electricity to be passing in the second coil of fine wire. Yet observe, this secondary fine coil has no connection whatever with the battery, and is also entirely insulated from the wire of the main coil over which it is wound; no current passes except at the moment contact is broken or renewed between the battery and the primary coil. A simple way of causing a rapid succession of currents to pass is to attach one end of the battery wire to a file by twisting it round it at the tang, and then taking the end of the primary coil and running it down the teeth of the file. A stream of sparks will be produced, and the needle will oscillate with great rapidity, as contact is made and broken at every tooth of the file over which the wire passes. Instead of the galvanometer as a test of the passing current, the latter may be detected in another way which will afford very tangible proofs of its existence. The ends of the fine wire having had about six inches of the silk or cotton covering removed, are to be wrapped round two pieces of sponge, which should be wetted with salt and water, and grasped firmly one in each hand. Let some one now make contact with the file as before. A succession of shocks more or less painful will pass through the arms and hands, the sensation being much like a repeated series of cramps or spasmodic contractions of the muscles, far from pleasant, and the worst of it is, that if the current is a strong one there is no power to relax the grasp and drop the sponges. I might tell you boys a tale of my own early freaks in electricity. Well, it was no great misdeed, but only of a bit of rather cruel fun which I had in company with a young doctor, almost as much of a boy as I was myself at the time.

The aforesaid doctor had a groom, who was also a sort of man-of-all-work, carrying out medicine, helping to pound drugs, and to hold refractory patients who objected to surgical operations. This man had but one eye of any practical use, for though the other was there, it was opaque and sightless, with a tendency to squint, which gave to the face a most grotesque appearance. The doctor had recently purchased a battery and coil for experimenting on cases of rheumatism, and the force of the shock could be regulated to great nicety, from such as a strong man would hardly care to try as an amusement, to such as would not injure a delicate child. Such instruments are common enough now, but were then not generally known, and somewhat expensive. After dining one day with the doctor, I began inquiring about his instruments and so forth, as I was fond of surgical matters, and used to find great delight in overhauling cases of instruments of torture. At last I got hold of his new galvanic apparatus, which he essayed to explain; but, except a dog and an old Tom-cat, we could find no suitable subject for experiments which we graciously declined to try upon our own august persons. All at once we espied Thomas, who had just returned from carrying out a basket of drugs. Poor Thomas! Little experience had he of galvanism, but I think he had a lesson on that eventful day. Suffice it that we got him to lay hold of the sponges, and we turned on the full power of the battery. He wriggled, he twisted, he fairly roared—and so did we, but at last the wire gave way and he was free. And now, boys, I must ask to be free too, for we have had a good many hours together over various mechanical subjects, and once more I must say "Adieu." Possibly I may address you, however, once more, and detail a few more of our early experiments as

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