"Here's a go!" observed that scion of a legal house. "Miss Lyte is telling them a fine cock-and-a-bull story up stairs; or else the story we have always believed is a pack of lies. She says *that Bedford Lyte* never ran away with Eleanor at all; that Sir Thomas Balbry had more to do with her ruin than any one else. And the old lady took hold of my jacket, and *made* me stay to listen to her. And she has shown them all a letter from Lady Balbry which has made them believe every word she says."

"Did you see it?" Robert asked.

"Yes; but I hadn't a chance of reading it. Blanche and Janet were poring over it together, and Blanche is as pale as a ghost."

"Is the governor up stairs?" asked Frank.

"No," Hubert replied. "But the worst of it is, Janet vows she will give all her fortune to *that* Bedford Lyte as soon as she comes of age."

"I'm hanged if she does," says Frank, with considerable emphasis, and leaves the room, grinding his teeth.

THE FIRST CENTURY OF THE REPUBLIC.

[Third Paper.]

MECHANICAL PROGRESS.—II.

IRON.

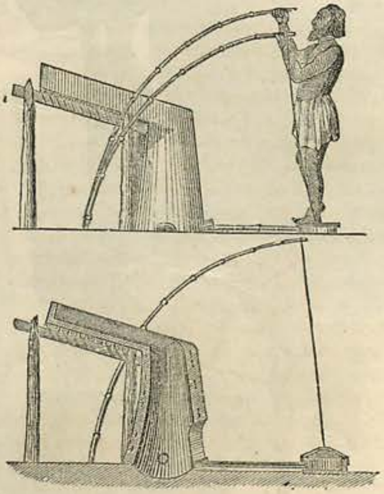
EARLY memorials point to the use of stone and flint, of copper and bronze, before the era of iron commenced, though the extraction of iron from its ore and its forging into shape antedate the historic period. Moses and the Hebrew chroniclers, 1450–700 B.C., Job, Homer, Ezekiel, Hesiod, Aristotle, Thucydides, Xenophon, Diodorus, and Pliny refer to the metal. It has been found by Belzoni, Vyce, Abbott, and Mariette in positions which indicate its use at the building of the Pyramids and the erection of the Sphinxes, and by Layard at Nimroud. The production of iron in large quantities is, however, quite recent, and the casting of it was an unexpected result incident to the enlargement of the furnace, the increased power of blast, and perhaps in part to the working of certain ores which were not so tractable under rude methods.

Pure iron is almost infusible, and the ancient processes succeeded in reducing the metal to a spongy condition, the impurities being removed by fluxes in the form of a slag, and by subsequent hammering and reheating. The product was a steel, and was produced in one process from the ore. In many parts of the world very widely separated the same means were used. In small cold-blast furnaces rich ore is heated in contact with incandescent charcoal, the viscid mass being hammered to remove earthy impurities. This plan is yet practiced in India, Africa, Malaya, Madagascar, and formed the

> "Mass of iron, shapeless from the forge,"

offered by Achilles as a prize at the funeral games of Patroclus, recorded in Homer's *Iliad.*

Dr. Livingstone refers to the iron-smelting furnaces of the tribes encountered in his *Expedition to the Zambesi.* The articles produced by these peoples are hammers, tongs, hoes, adzes, fish-hooks, needles, and spear-heads. The *assagais* of the Caffres are made of iron similarly procured, and of excellent quality. The *wootz* of India is still produced in the manner partially described by Aristotle when speaking of India, and by Diodorus Siculus, referring to the iron ores of the island of Ethalia.



IRON FURNACE OF THE KOLS, HINDOSTAN.

Our illustration represents a blast-furnace of the Kols, a tribe of iron smelters in Lower Bengal and Orissa. The men are nomads, going from place to place, as the abundance of ore and wood may prompt them. The charcoal in the furnace being well ignited, ore is fed in alternately with charcoal, the fuel resting on the inclined tray, so as to be readily raked in. As the metal sinks to the bottom, slag runs off at an aperture above the basin, which is occupied by a viscid mass of iron. The blowers are two boxes with skin covers, which are alternately depressed by the feet and raised by the spring poles. Each skin cover has a hole in the middle, which is stopped by the heel as the weight of the person is thrown upon it, and is left open by withdrawal of the foot as the cover is raised.

Variously modified in detail and increased in size, these simple furnaces are to be found in several parts of Europe, the Catalan and Swedish furnaces resembling in all probability those of the Chalybes, so famous in the time of Marathon (490 B.C.), and those of the *fabrica* or military forge established in England by Hadrian (A.D. 120) at Bath, in the vicinity of iron ore and wood. The brave islanders met their Roman invaders with scythes, swords, and spears of iron, and the export of that metal from thence shortly afterward is mentioned by Strabo.

During the Roman occupation of England some of the richest beds of iron ore were worked, and the *debris* and cinders yet exist to testify to two facts—one, that the amount of material treated was immense; the other, that the plans adopted were wasteful, as it has since been found profitable to work the cinders over again.

During the Saxon occupation the furnaces were still in blast, especially in Gloucestershire.

The early Norman sovereigns were so intent upon skinning the Jews and Saxons that it became dangerous to succeed in any business, success inviting the barons to plunder. Accordingly we find in the time of King John that iron and steel were imported from Germany.

The business lumbered along for some centuries, the government tinkering at it now and again, the exportation being prohibited in the fourteenth century, and the importation of iron in the fifteenth century.

The direct method of obtaining wrought iron from the ore prevailed until the commencement of the fifteenth century, and then gradually gave way to a less direct process, but one more convenient in the handling of large quantities. Furnaces, operating by the aid of a strong blast, to *melt* the iron and obtain *cast iron*, which is carbureted in the process, were in use in the neighborhood of the Rhine about 1500. A second process in a *forge* hearth was used to eliminate the carbon and other impurities, and the result was *wrought iron*.

The statement is shortly made, but it took several centuries to accomplish it with wood, and several other centuries to devise means for substituting pit-coal for charcoal.

In the reign of Elizabeth blast-furnaces were of sufficient size to produce from two to three tons of pig-iron per day by the use of charcoal. In the small works the iron was made malleable before being withdrawn from the blast-furnace, and in larger works was treated by the refinery furnace.

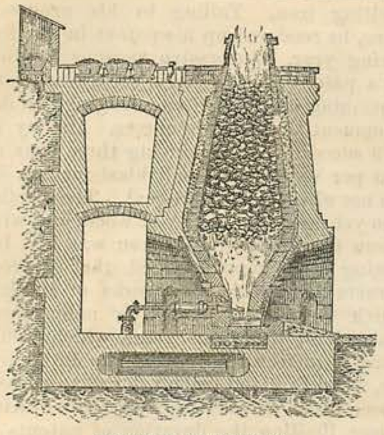
Wood becoming scarce, and a number of furnaces having gone out of blast, in 1612 Simon Sturtevant was granted a patent for thirty-one years for the use of pit-coal in smelting iron. Failing in his proposed plans, he rendered up his patent in the following year. Successive persons applied for a patent for the same, the government continuing desirous of encouraging the development of home resources. Dudley in 1619 succeeded in producing three tons of iron per week in a small blast-furnace by the use of coke from pit-coal. The parties who yet possessed plenty of wood, and with whom the production of iron was fast becoming a monopoly, urged the charcoal burners to destroy the works of Dudley, which was done. Dudley's patent was granted for thirty-one years, which would bring it to 1650, the time of the Protectorate, when England had a ruler fit to succeed Queen Bess. The celebrated statute of King James, limiting the duration of patents to fourteen years, was passed in 1624. Dudley's petition for an extension was refused.

Iron of poor quality continued to be made in districts where wood was scarce, and of good quality from charcoal in places where forests yet remained. The demand for iron continuing to grow—a natural effect of advancing civilization—iron was imported from Sweden and Russia in large quantities and of excellent quality. The forests of these countries gave them a natural advantage over England, whose forests had by this time become thinned out, so that the use of wood for iron smelting had been forbidden by act of Parliament in 1581 within twenty-two miles of the metropolis or fourteen miles of the Thames, and eventually was prohibited altogether.

The art of making iron with pit-coal and of casting articles of iron was revived by Abraham Darby, of Colebrookdale, about 1713, and was perseveringly followed, although it was but little noised abroad. In the *Philosophical Transactions* for 1747 it is referred to as a curiosity.

The extension of the iron manufacture dates from the introduction of the steam-engine, which increased the power of the blast, and the blowing engines, driven by manual, horse, or ox power, were henceforth operated by steam-engines. The dimension of the blast apparatus was increased from time to time, and about 1760 coke was commonly used in smelting. In 1760 Smeaton erected at the Carron Works the first large blowing cylinders, and shortly after Boulton and Watt supplied the steam-engines by which the blowers were driven. Neilson, of Glasgow, introduced the hot blast in 1828. Aubulos, in France, in 1811, and Budd, in England, in 1845, heated the blast by the escaping hot gases of the blast-furnace. In the smelting of iron four tons weight of gaseous products are thrown off into the air for each ton of iron produced.

As a means of estimating by comparison the value of the hot blast, some facts may be



MODERN BLAST-FURNACE.

mentioned. Mushet states that at the Clyde Iron-works, before the introduction of the hot blast, the quantity of materials necessary for the production of one ton of pig-iron was,

Calcined ore	1¾ tons.
Coke	3 "
Limestone	½ ton.

In 1831, when the system was coming into use, the blast being *warm*,

Calcined ore	2 tons.
Coke	2 "
Limestone	½ ton.

In 1839, with a hot blast,

Calcined ore	1¾ tons.
Coke	1¾ "
Limestone	½ ton.

The saving in fuel being nearly one-half.

In addition may be mentioned the fact that anthracite coal and black band ore are intractable under the cold blast, but the former yields an intense heat and the latter a rich percentage of good iron with the hot blast.

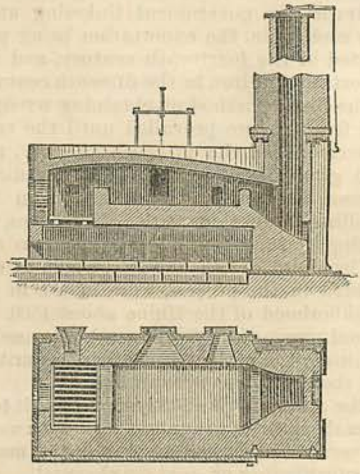
The Calder Works in 1831 demonstrated the needlessness of coking when the hot blast is employed.

Experiments in smelting with anthracite coal were tried at Mauch Chunk in 1820, in France in 1827, and in Wales successfully by the aid of Neilson's hot-blast ovens in 1837. The experiment at Mauch Chunk was repeated, with the addition of the hot blast, in 1838–39, and succeeded in producing about two tons per day. The Pioneer furnace at Pottsville was blown-in July, 1839.

The first iron-works in America were established near Jamestown, Virginia, in 1619. In 1622, however, the works were destroyed and the workmen with their families massacred by the Indians. The next attempt was at Lynn, Massachusetts, on the banks of the Saugus, in 1648. The ore used was the bog ore, still plentiful in that locality. At these works Joseph Jenks, a native of Hammersmith, England, in 1652, by order of the Province of Massachusetts Bay, coined silver shillings, sixpences, and threepences known as the "pine-tree coinage," from the device of a pine-tree on one face. The coinage of these pieces by Massachusetts excited the ire of the king, who, as Junius said to the Duke of Grafton, "left no distressing examples of virtue even to [his] legitimate posterity." The king indignantly declared to Sir Thomas Temple that they had invaded his prerogative by coining money. Sir Thomas, who was a real friend to the colonies, took a piece out of his pocket and presented it to the king. "One side was a pine-tree of that kind which is thick and bushy at the top. Charles asked what that was. 'The royal oak, Sir, which preserved your majesty's life!' The king resumed his good humor, calling the colonists a 'parcel of honest dogs.'"

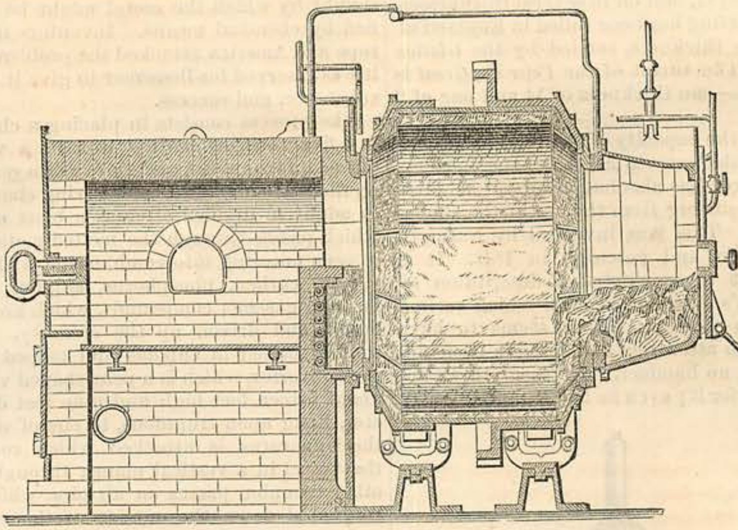
By dint of successive efforts, cast iron was produced in something like sufficient quantities to meet the demand, the furnaces enlarging as the blowing engines increased in power.

The next step was to simplify and expedite the processes by which the cast iron was made malleable. In 1780, two years before the conclusion of the peace between Great Britain and the Federal government, Henry Cort invented the puddling furnace, which he patented in 1784, and which revolutionized the business of making malleable iron.



PUDDLING FURNACE.

The charge of iron, say 540 pounds, is placed on a hearth in a reverberatory chamber whose bottom and sides are lined with refractory slags rich in oxide of iron. When the iron is melted, the slags rise through it and float on the top. The oxygen in the silicates combines with the carbon in the iron, decarbonizing it, the puddler stirring it vigorously to bring the carbon and other impurities of the iron in contact with the



DANKS'S MECHANICAL PUDDLER.

oxidizing flame. The iron granulates and throws off carbonic oxide, and eventually agglutinates, or, as the puddler says, "comes to nature." A deoxidizing flame is then used to protect the iron while it is being made into balls, which are shingled or squeezed to remove slag and compact it for rolling. The bed of Cort's furnace was of sand. Rogers, some years afterward, made the bottom of iron, and lined it with cinder.

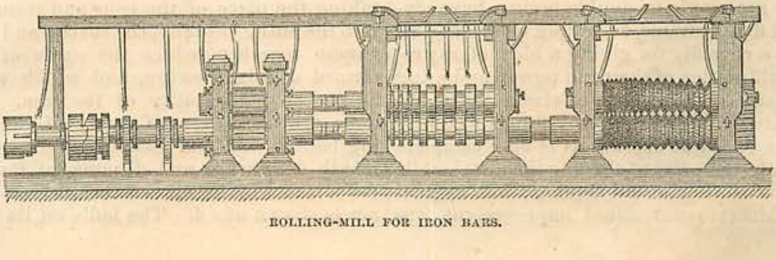
The operation of puddling is a great tax upon the strength and endurance of the men, both on account of the violent labor and of the exposure to the intense heat of the furnace.

Mechanical puddlers have been substituted for hand labor with some success. The rotating hearth of Danks, of Cincinnati, has attained more celebrity in this country and in England than any other furnace for that purpose. The barrel-shaped chamber lined with refractory material is placed between the furnace and the chimney, and the iron, after it has become melted, is rolled round and round as the chamber revolves, and thereby all parts are in turn exposed to the action of the flame.

The *ball* from the puddling furnace is dragged or rolled to the steam or trip hammer or the squeezer, where it is compacted and has the dross driven out of it, making a *bloom*. In this condition it is shipped from some iron-works, while others carry it a step farther before putting it upon the market.

Here occurred the next great necessity. Was the bar-iron always to be brought to shape by the hammer alone? Again Cort came to the rescue with the invention of the mill with grooved rollers, which he patented in 1783. The yearly value of this improvement in England and the United States amounts to hundreds of millions of dollars.

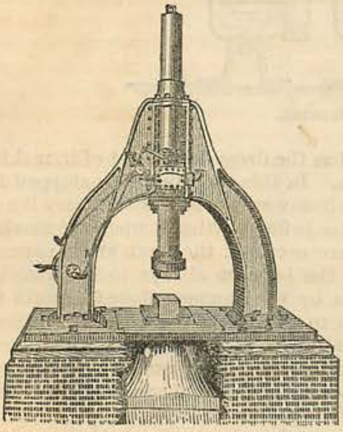
Years after the death of the unrewarded Cort the rolling-mill was made to form plates for armor of ships of war. In 1842 the late R. L. Stevens, of Hoboken, New Jersey, commenced the construction of an iron-clad war vessel under an agreement with the government, which has not yet been completed. In 1855 some armor-clad floating batteries were used by the French in the Black Sea. The *La Gloire*, launched in 1859, was plated with rolled iron of 4½ inches thickness, and was the first large iron-clad. The first English armored vessel, the *Warrior*, had the same thickness of armor. The thickness has since been much increased: the *Bellerophon* has 6 inches, the *Hercules* 9, *Peter the Great* (Russian) 12 to 14. The plating of the *Monitor* turret was 9 inches, the



ROLLING-MILL FOR IRON BARS.

Weehawken 11, laid on in several thicknesses. Armor plating has been rolled in England of 15 inches thickness, carried by the *Glatton* turret. The turret of the *Peter the Great* is 16 inches—one thickness of 14 and one of 2 inches.

While the capacity of the rolling-mill has seemed adequate to all calls, the business of the forge has also had its grand achievements, resulting from the use of the steam-hammer. This was invented by Nasmyth about 1838, and patented in 1842. It is true that there existed a description of Devereau's hammer in 1806 which recited the main features, but it seems to have excited no attention, and to have been followed by no hammer. To Nasmyth we are indebted for it; even he had to work against prejudice, which prevented its being used in England until after it had been tried in France by some more appreciative persons, whose attention had been in some way directed to it.

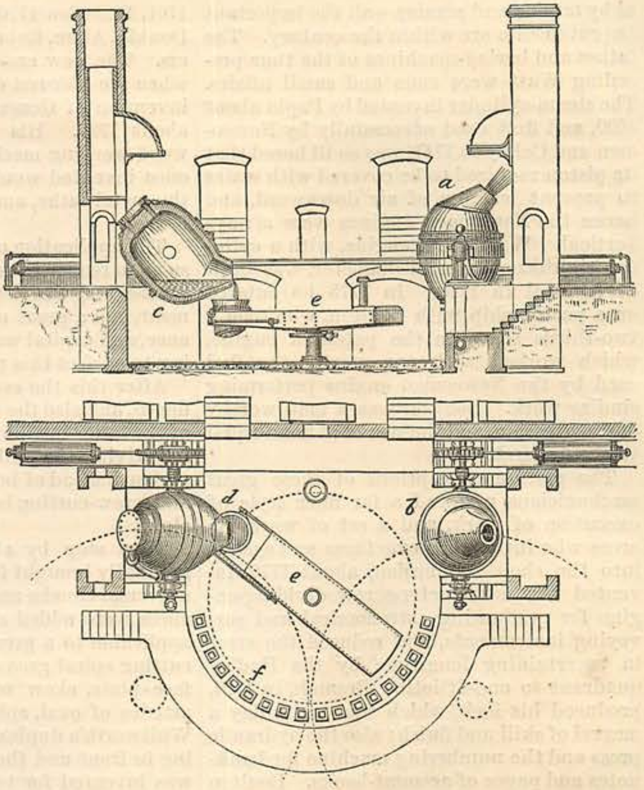

NASMYTH'S DOUBLE-FRAME STEAM-HAMMER.

The helve of the steam-hammer is the piston-rod of an overhead steam-engine, by which it is lifted. To drop it, the steam which lifted it is allowed to escape from below the piston, and the force of the blow is, in some hammers, increased by admitting the steam above the piston, which adds the force of the steam to that due to the weight and fall of the hammer. The sizes vary, having a very wide range, the weight of the hammer varying from 50 pounds to 80,000 pounds, the stroke from six inches to six feet. They are single or double acting, have single or double frame, according to size, and all have a capacity for giving a blow of any required fraction of their full power, and using any part of their range of stroke. The anvils are made as heavy as 250 tons weight.

The series of operations is here complete down to the point of shaping the metal while hot by rolling or by forging; but a great and hitherto unrealized improvement was sought by which the metal might be purified by chemical means. Inventors in Europe and America attacked the problem, but it was reserved for Bessemer to give it form, substance, and success.

The process consists in placing a charge, say five tons, of molten iron in a vessel placed on trunnions, and known as a *convertor*, the bottom of the vessel having channels to admit in divided streams a blast of air which passes through the melted metal, its oxygen entering into combination with the silicon, carbon, phosphorus, sulphur, etc., forming gaseous compounds, which are liberated and driven up the chimney. The iron is melted in cupolas and tapped into the convertor, which is a pear-shaped vessel about fifteen feet high and nine feet diameter, hung upon trunnions, to one of which the apparatus is attached which rotates the vessel in a vertical plane; through the other trunnion passes an air-pipe which is continued down the outside of the vessel and opens into a chamber at the bottom which communicates with the main chamber through 120 holes, each three-eighths of an inch in diameter. These holes are in fire-bricks, and the vessel itself is lined with refractory material.

The vessel is turned partly down, the mouth being presented upwardly to take its charge from a ladle suspended from a crane and sweeping in the arc of a circle between the cupola and the convertor. The blast is then turned on, the vessel righted, the air pressure preventing the iron entering the blast holes, and the spout being presented to a canopy which leads the evolved gases up the chimney: this is shown at *a b*, page 217. The silicon of the pig-iron oxidizes first without very intense flame, but as the carbon begins to burn the heat rises to 5000° Fahrenheit, and the light is so brilliant as to cast shadows across sunshine. In fifteen or twenty minutes the marvelous illumination ceases more suddenly than it began, and this change in the flame indicates the critical moment of the elimination of most of the carbon. The blast is stopped, the convertor turned on its side, and six hundred pounds of melted spiegeleisen are turned in. The reaction is instantaneous and violent. The manganese of the spiegeleisen combines with any sulphur that may remain in the bath, forming compounds which pass into the slag. It also decomposes in the slag silicates of iron, taking the place of the iron and returning it to the bath. Finally, the carbon and manganese together reduce the oxide of iron formed during blowing, and which would affect the malleability of the iron. This done, the monster, as if weary of swallowing boiling iron and snorting fire, turns its mouth downward and disposes of its contents into a kettle upon a turn-table. This act is shown at *c d*. The ladle on its turn-table *c* is then swung over the moulds *f*, ranged round the semicircular pit like a row of Ali Baba's wine jars, each capable of holding a bandit. The glowing metal is drawn into the moulds from a tap hole in the ladle, and as each mould is filled the molten metal is covered with a steel plate and a packing of sand. When the ingots have solidified they are tipped out of the moulds and carried away by tongs or traveling cranes to the shops, where they are hammered or rolled into the required forms of bars, rails, plates, and what not. The product is usually a grade of steel, though the quality may be varied by changes in the details of the process.



BESSEMER PLANT.

Like Arkwright, Bessemer has become very wealthy, and for every dollar he has made, his country has been enriched by hundreds. The actual working process in America has been materially improved by Mr. Holly, who is consulting engineer of the principal Bessemer works in this country.

This was a great improvement for most purposes over the old process of cooking the iron in the puddling furnace to deprive it of its silicon and carbon, tilt-hammering the ball to a bloom, rolling the bloom to a bar, cutting the bar in pieces, and building it with charcoal solidly into a cementation furnace, where it might absorb carbon to constitute it steel. This old process is still pursued for the finer qualities, the blister-steel produced from the cemented bar being several times worked before it becomes the best cast steel for our finest cutlery. The process of making cast steel was invented by Benjamin Huntsman, of Ottercliff, near Sheffield, England, in 1770, so that this great invention comes practically within the century. The blister-steel is broken into pieces, fused in crucibles of refractory clay or graphite, made into ingots in cast-iron moulds, and then rolled.

But the convenience of casting iron into shape, instead of laboriously forging it into the varied and sometimes difficult forms required, is so great that a process for making cast-iron articles malleable became a great necessity. This was invented in Sheffield by Samuel Lucas, and patented by him in 1804. The process is as follows: The castings are inclosed in iron boxes, and surrounded with pounded iron-stone or some of the metallic oxides, as scales from the forge, common lime, or other absorbents of carbon, used either together or separately. The boxes are placed in the furnace, subjected to a strong heat for about five days, and allowed to cool gradually within the furnace. The time and other circumstances determine the depth of the effect. Thin pieces become malleable entirely throughout, admit of being readily bent, and may be slightly forged; thicker pieces retain a central portion of cast iron, but in a softened state, and not so brittle as at first. On sawing them through, the exterior coat of soft metal is perfectly distinguishable from the remainder.

In the processes of hand forging, annealing, and tempering we have nothing to claim over the methods or the productions of former ages and other nations, such as the Arabs and Persians.

As with the processes involving the *production* and *refining* of iron, and the shaping of the heated metal by *casting, forging,* and *rolling,* so with the shaping of the cold metal by *turning* and *planing*—all the important improvements are within the century. The lathes and boring-machines of the time preceding Watt were rude and small affairs. The steam-cylinder invented by Papin about 1690, and first used successfully by Newcomen and Calley in 1711, was so ill bored that its piston required to be covered with water to prevent leakage of air downward, and hence the Newcomen engines were always vertical. Watt's first engine, with a cylinder eighteen inches in diameter, was built at Kinneal in 1770. In 1775 he entered on a partnership with Boulton, who took a two-thirds share in the patented engine, which worked with one-quarter the fuel used by the Newcomen engine performing similar work. Boulton was a man worthy of the occasion, and the works at Soho equal to the demand.

The mature conceptions of these great mechanicians required a far finer style of execution of work, and a set of workmen arose who introduced exactness and system into the shop. Ramsden, about 1770, invented the micrometer-screw dividing-engine for graduating astronomical and surveying instruments, and reduced the error in ascertaining longitude by the Hadley quadrant to one-fiftieth. Bramah, in 1784, produced his lock, which was in its day a marvel of skill and finish; also the hydraulic press and the numbering machine for bank-notes and pages of account-books. Boulton and Watt, in 1788, were celebrated for the perfection of their mint apparatus, coining the silver of the Sierra Leone Company, the copper of the East India Company, and sending two complete mints to the Emperor Paul I. of Russia. In Bramah's workshop Clement and perhaps Maudslay were trained, one the inventor of the planing-machine, the other a builder of marine engines, who gave them shape when as yet steam navigation was in its infancy. Roberts of Manchester gave his attention to the perfecting of machinery for working in fibre, Whitworth especially to machine-tools and instruments for measuring with mathematical accuracy. We shall have occasion to mention presently the perfecting of the modes of manufacture, and to show the part America took in the matter.

The first turning-lathe was vertical—the potter's wheel—and was employed upon plastic material. After many centuries of use in this way, the spindle was made horizontal, and it was employed on wood. Its use on metal is comparatively modern. The screw lathe is still more recent. One is described in a French work of 1578, and another in an English work of 1694. They were, however, rather bench tools for watch-makers and jewelers than machines. The work of originating correct screws, and perfecting the screw-cutting lathe, was taken in hand by Plumier 1701, Ramsden 1770, Robinson of Soho 1790, Donkin, Allan, Roberts, Whitworth, and others. The new era of the lathe commenced when the *slide-rest* was added. This was the invention of General Sir Samuel Bentham, about 1791. His particular *forte* was in wood-working machinery, but the slide-rest once invented would be readily adapted to the metal lathe, and the *slide lathe* soon followed.

The application of a *screw* to the *slide lathe* so as to render it capable of both *sliding* and *screw-cutting* was the next important improvement, and a great amount of time, perseverance, and capital was expended in endeavoring to perfect this portion of the lathe.

After this the *surfacing motion* was introduced, and also the use of a shaft at the back of the lathe, in addition to the regular screw, for driving the sliding motion by rack and pinion, instead of both the motions of sliding and screw-cutting being worked by the screw alone.

Thus step by step improvements were gradually brought forward; the fore jaw and universal chucks and other important appliances were added so as to render the lathe applicable to a great variety of work, even cutting spiral grooves in shafts, scrolls in a face-plate, skew wheels, and also turning articles of oval, spherical, and other forms. Whitworth's duplex lathe, with one tool acting in front and the other behind the work, was invented for turning long shafts, cast-iron rollers, cylinders, and a great variety of work where a quantity of the same kind and dimensions has to be turned.

The planing-machine was an outgrowth of the slide lathe. Instead of the object turning upon centres against a tool, it is dogged to a traversing-table and moves against the tool in a right line. This machine-tool has dispensed to a great extent with chipping and filing, and is at the bottom of all successful fitting of machinery. It is next in importance to the lathe. It was invented about 1820, several excellent mechanics having about the same time worked at and solved the problem—Clements, who was a workman in Bramah's shop, Fox of Derby, Roberts and Rennie of Manchester. Bramah had, as far back as 1811, employed the revolving cutter to plane iron, adapting to metal the form previously used on wood-planing machines; this is the milling-machine lately so much improved and so deservedly esteemed.

The first planing-machines were moved by a chain winding on a drum; the rack and pinion, and eventually the screw arrangement, were substituted. Clements's machine, described in his letter to the "Society of Arts" (vol. xlix., p. 157 *et seq.*), included the reciprocating bed, guided and moved horizontally and automatically with a greater or lesser stroke. It had two cutters capable of being directed backward and forward, and at different elevations, so as to cut at each motion of the bed. The cutters were fixed in a sliding head, and were shifted automatically at the end of each stroke, horizontally or vertically. The cutters could be canted to any angle to plane either side of the work. It was, in fact, the planing-machine of the present day.

The next great improvement in the machine was the "Jim Crow" planer of Joseph Whitworth, of Manchester, 1835. This has the self-reversing cutter, which "wheeled about and turned about and did just so," operating both backward and forward with one tool without waste of time.

Other adaptations known by special names can not be overlooked. The *jack*, a small machine, named from its quick, handy ways and compact form. The *slotting*-machine and the *key-grooving* machine, by Roberts of Manchester, have mortise chisels reciprocated vertically by an eccentric, while the wheel to be slotted is laid horizontally on the lathe and fed toward the cutter between each stroke. The *milling*-machine has been referred to. It is only of late that it has been esteemed as it deserves and made much use of. The *shaping*-machine is one in which the object is chucked on a mandrel, the tool traverses above the work in a line parallel with the axis of the mandrel; the latter being slightly rotated between each stroke constitutes the feed, and the result is a circular or curved shape attained by straight cuts.

The machine-tools of the present day are a marvel, and the work turned out by them excels in quality and quantity any thing conceivable by the worthies of the first part of the present century. Watt, for instance —to select the most prominent of the men who combined to revolutionize the world of industry while smaller men were making all the noise in the manufacture of "holy alliances" which hardly survived their framers —Watt would have been infinitely gratified and astonished at the development and perfection of the machine-tools of the present day. He would see in them the cause and the effect; the ponderous and yet delicate machines driven by the engines which they had created; the tools the makers and yet the agents; the engines the movers of the tools by which they came to exist; their growth parallel in fitness, proportion, and magnitude, which are the elements of beauty, grace, and majesty.

A word as to the constitution of the machines themselves, of the means by which they are fashioned and adapted to perform their specific duties with smoothness, directness, and economy of power.

The system of making the component parts of a machine or implement in distinct pieces of fixed shape and dimensions, so that corresponding parts are interchangeable, is known as *assembling*. The term is, however, more strictly applicable to their fitting together after being separately and accurately made according to fixed patterns, and constantly compared by gauges and templates which test the dimensions.

This system of interchangeability of parts was first introduced into the French artillery service by General Gribeauval, about 1765. He reduced the gun-carriages to classes, and so arranged many of the parts that they could be applied indiscriminately to any carriage of the class for which they were made. The system was afterward extended into several of the European services and into that of the United States.

The first fire-arm attempted to be made on this system was the breech-loader of John H. Hall, of North Yarmouth, Massachusetts, 1811, of which 10,000 were made for the United States, $10,000 being voted the inventor in 1836, being at the rate of one dollar per gun. Some of them were captured in Fort Donelson, February 16, 1862. They were probably the first breech-loading military arms ever issued to troops.

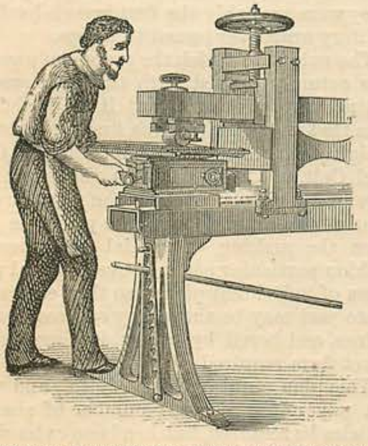
The extent to which the system of gauges was actually carried with the Hall arm is not accurately known, but it is doubtless true that the principle was first brought to a high state of system and accuracy by Colonel Colt, of Connecticut, in the manufacture of his pistols. Among the most important of the extensions of the principle has been the making of special machines to fashion particular parts, or even special portions of individual pieces, so that each separate part may be shaped by successive machines, and bored by others, issuing in the exact form required.

This plan requires large capital, and will not pay unless a great number of similar articles be required, but has been extensively introduced into this country, and from hence into England, and to some extent on to the continent of Europe. All the government breech-loading fire-arms are thus made. The greater number of the military arms of Europe and Egypt are thus made in the United States for the various countries. The Snider gun, a modification of an American model, is made at the Enfield Arsenal, England, on special machines made for that purpose in duplicate at the Colt Works, Hartford, Connecticut. Pratt and Whitney, of Hartford, are just completing for Germany a full set of special machines and gauges for the manufacture of the Mäuser rifle, adopted by Prussia for the confederate German States.

The first watch made on this plan was the "American" watch of Waltham, Massachusetts, the system extending down to the almost microscopic screws and other small parts. All the prominent sewing-machines are so made; the same with Lamb's knitting-machine, and probably others. Many kinds of agricultural implements, including plows, harvesters, threshers, and wagons, are made of interchangeable parts. The system has been carried into locomotive building; about seven grades of engines, it is understood, are employed on the Pennsylvania Central Railroad, corresponding parts of a given grade being precisely similar, so as to fit any engine of the class. This is the American system of *assembling*.

While upon the subject of instruments of precision, one or two instances may be given where the result was a marked success and affected large interests.

The American system of bank-note engraving is the invention of Jacob Perkins, of Newburyport, Massachusetts, in 1837. Previous to his time the engraving, whether of ornament or lettering, had been simply cut by hand upon the plate, which was then printed in the copper-plate press. Perkins's system is to engrave the design on separate blocks of softened steel, which are subsequently hardened. Each block so engraved is used to make a raised impression on a softened steel roller, which is rocked upon it under very heavy pressure. The roller is then hardened, and is used as a roller die to impress the steel plate from which the notes are printed. Each part of the face and back of the note is upon one or another of the roller dies, whose separate impressions upon the plate combine to make up the whole design, roller after roller being used after adjustment to its proper place over the plate. The table is provided with complete adjustments of peculiar delicacy.



PERKINS'S TRANSFERRING PRESS AND ROLLER DIE.

The invention was introduced into England by Perkins, but did not become popular. In Ireland it fared better. In this country it is supreme.

Postal and revenue stamps are so made in all instances. England makes them for the varied and widely separated nations of her vast empire. America, which originated the system, makes them for other nations in all quarters of the globe. The postal stamp itself, though now a necessity, is an affair but of yesterday, as it were, and was an outgrowth of cheap postage, for which let us thank Divine Providence and Rowland Hill.

Another triumph of the century is the watch. The invention of the compensation-balance of John Harrison covered the period 1728–1761. He died in 1776. Arnold and Earnshaw brought it to something near perfection. Harrison's fourth chronometer was sent in a man-of-war to Jamaica, which it reached five seconds slow. On the return to Portsmouth, after a five-months' voyage, it was one minute and five seconds wrong, showing an error of sixteen miles of longitude, and within the limit of the act of Parliament of Queen Anne, passed in 1714. This amount of accuracy has since been very much exceeded. He received the grant of £20,000 in installments, the reward of forty years' diligence.

The American system of watch-making, by gathering all the operations under one roof, making the parts as largely as possible by machinery, each part being made in quantity by gauge and pattern, and the pieces afterward *assembled*, dates back to 1852, but was afterward perfected, and the number of parts reduced from 800 to 156. In the year mentioned A. L. Denison and three coadjutors started the business in Roxbury, Massachusetts, thence moved to Waltham, Massachusetts, where the business now occupies a large factory, employs 700 hands, and turns out 80,000 watches annually. This is the pioneer establishment. Others are in operation at Elgin, Illinois; Springfield, Massachusetts; Newark and Marion, New Jersey.

Achromatic lenses were first made by John Dollond, of London, 1758. The discovery rendered the telescope of high powers possible. Without going into the optical principles involved, it may be stated that with refracting telescopes before Dollond an instrument of quite moderate magnifying power was 100 feet long. The equatorial of the Washington Observatory is the largest refractor in the world. It was made by Alvan Clark and Sons, of Cambridgeport, Massachusetts, the glass being cast by Chance and Co., of Birmingham, England. It was mounted in November, 1873, is thirty-two feet long, and, last and most important of the statement, it has an objective of twenty-six inches diameter.*

With two other instruments of precision

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* An illustration of this equatorial may be found in *Harper's Magazine* for March, 1874, p. 535.

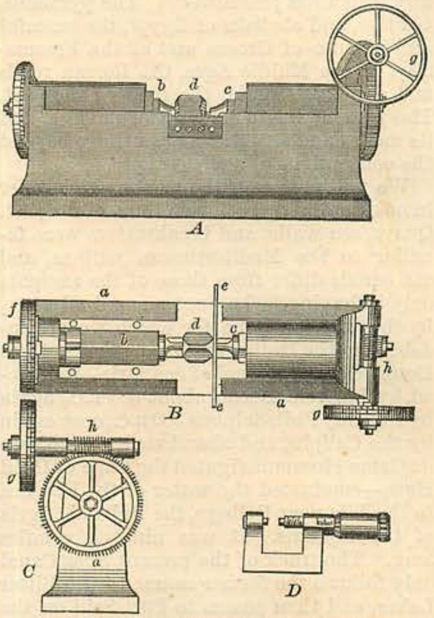
we may close this part of the subject, both means for accurate measurement:

1. The *contact level* invented by Repsold, of Hamburg, in 1820, as improved by Würdemann, of Washington. It is an adaptation of the spirit-level, for the production of exact divisions of scales, and for the determination of very minute divisions of length. It consists of a delicate level pivoted at its middle and across its length with a small tilt weight at one end, which tips always in one direction. From the centre of the level downward extends a short rigid arm, with a plain polished surface perpendicular to the chord of the level against which the contact is made. The carrier of this instrument is either fixed or mounted in a slide governed by a micrometer screw. If, now, the end of a rod terminating in a hardened steel point be advanced horizontally till it bears against the contact arm, the level will gradually assume the horizontal position, and the movement of the bubble, as indicated by the scale upon the glass, will depend upon the relation of the radius to which the level tube is ground and the length of the contact lever. If the latter be half an inch long, and the radius of the glass tube be 400 feet (levels for astronomical purposes are ground to a sweep of 800 and 1000 feet radius), the relation between the lever and radius is as 1 to 9600, and as $\frac{1}{50}$ of an inch can be readily read from the lever scale, $\frac{1}{480000}$ of an inch (9600×50) will be the difference in length which each such division on a scale indicates.

2. Whitworth's micrometer gauge is capable of measuring to $\frac{1}{1000000}$ of an inch. The principle of its action may be readily understood by the micrometer screw D, which is a pocket instrument made to measure to $\frac{1}{1000}$ of an inch. The screw has fifty threads to an inch, the head having twenty divisions on its circumference; consequently a turn of the head through one division advances the screw $\frac{1}{50} \times \frac{1}{20} = \frac{1}{1000}$ of an inch.

The millionth measuring instrument, shown by three views, A, B, C, has two head stocks with a V groove between them, in which the square bars *b* *c* are laid, as is also the standard of the bar *d*, of which the length is to be tested. The sides of the groove and of the bars are worked up to as true a plane as possible, and are kept at right angles to each other. The ends of the bars are also made square with their sides, and brought to true planes, the ends being canted to present circular instead of square faces.

Through each head-stock runs an accurately pitched micrometer screw, by which *b* and *c* are driven along the groove. The screw on the side of *b* has exactly twenty threads to the inch, and is turned by the wheel *f*, the circumference of which is divided into 250 parts. Consequently, by turning the wheel forward one division the bar is moved $\frac{1}{5000}$ of an inch.



WHITWORTH'S MILLIONTH MEASURING GAUGE.

The other screw has a similar thread, is driven by a worm-wheel of 200 teeth, into which gears a tangent screw *h*, having fixed upon its stem the graduated wheel *g*. The circumference of this wheel being also divided into 250 parts, a movement of one division corresponds to a traverse of $\frac{1}{20} \times \frac{1}{200} \times \frac{1}{250} = \frac{1}{1000000}$ of an inch on the bar *c*. Fixed pointers enable the exact movement of wheels *f* or *g* to be read off, so that this extremely minute difference in the length of any bars may be detected, provided the micrometer screws exert an equal pressure in every case.

This equality of pressure is secured by a very simple and beautiful arrangement. Between one extremity of the steel bar under comparison and the sliding bar a small steel piece with true parallel sides is introduced. This piece is called the *feeler*, and its ends, *e* *e*, rest upon two supports on the sides of the bed. When little or no pressure is exerted on the bar *d*, the feeler falls back of its own weight if one of its ends is raised. A slight pressure prevents this falling back, and the friction between this piece and the ends of the bars becomes a very delicate measure of the pressure to which it is subjected.

ENGINEERING.

How shall we condense within the limits of the section of an article even a list of the engineering devices and expedients which distinguish the century nearly closed from any which has preceded it? The pyramids, temples, and obelisks of Egypt, the graceful architecture of Greece and of the Freemasons of the Middle Ages, the Roman roads and aqueducts, make the fame of the past. The present has a new set of devices, and its modes and structures are utterly beyond the conceptions of ancient times.

We will pass over the works which differ in no essential respect from those of the past. Quays, sea-walls, and breakwaters were familiar to the Mediterranean nations, and our canals differ from those of the ancients only in having locks—not a small advance, by-the-way, and one for which we are indebted to the Italian engineers, the brothers Domenico. The canal of Sesostris—re-opened by Pharaoh Necho about 605 B.C., again by Ptolemy Philadelphus 300 B.C., once again by the Caliphs, and abandoned when Vasco da Gama circumnavigated the Cape of Good Hope—conducted the water of the Red Sea to the Nile near Belbeys, the Bubastis Agria of the Romans. It was ninety-six miles long. The track of the present Suez Canal only follows the former course to the Bitter Lakes, and then passes to Port Said on the Mediterranean. The sand and earth of the old canal were drearily excavated by fellahs who toiled with wooden shovels and baskets. The steam-dredges of M. De Lesseps were sixty in number, of two kinds, and deposited the 400,000,000 cubic yards of mud and sand on banks at a regulated distance from the canal.

The Pharos of Alexandria, said to have been 450 feet high, was a beacon to the roadstead of Alexandria. This city was built by what might have seemed the whim of a man who in the plenitude of his power came to Rhacotis, a place occupied by a little group of hovels, and spread his Macedonian cloak on the ground for the plan of a city to bear his name. He saw it rise in his mind's eye, and gave his directions for the avenues, the Serapæum, the Bruchion, and other public buildings, took up his line of march for the teeming East, and never saw Alexandria. Yet posterity approved his judgment, and his city has embalmed his name.

One of our contributions in the line of light-houses is the dovetailed block system introduced by Smeaton in 1760 at the Eddystone, copied by the Stephensons at Bell Rock, in the Frith of Forth, and at the Skerryvores, and still later at Wolf Island. Others are the screw-pile and the truss-frame systems, which are convenient in many places where the column of masonry is not suitable. Farther, the mode of lighting is much more eminently superior to the past than is the mere structure. When Smeaton had finished the Eddystone it was lighted by twenty-four tallow-candles stuck in a hoop. Even the Tour de Corduan, put up with so much expense in 1610 at the mouth of the Garonne, was for a long time lighted with burning logs in a large cresset. The catoptric system of lamps with parabolic reflectors was introduced into the Tour de Corduan soon after the invention of the circular-wick and centre-draught lamp by Argand, of Geneva, in 1784—a lamp which made the effective illumination of light-houses possible.

The dioptric system, by lenses, was attempted in England at the South Foreland light in 1752 and the Portland light in 1759, but failed for want of skill. It was revived and improved by Fresnel in 1810. It was adopted in the Lundy Island light in 1834, and is the best light, having several grades of size, according to importance of position.

In pile-driving we have better machinery than the Romans, who, however, made good work in bridges built on piles, and in constructing coffer-dams for building stone piers in river-beds. Elm piles driven by the Romans at London were in good order when removed to build the abutments of London Bridge in 1829. Cæsar threw a pile and trestle bridge across the Rhine in ten days. Trajan's bridge across the Danube was 4770 feet long, having twenty semicircular arches of 180 feet 5 inches span each. The piers were of stone, the superstructure wood. There were also many bridges in Rome.

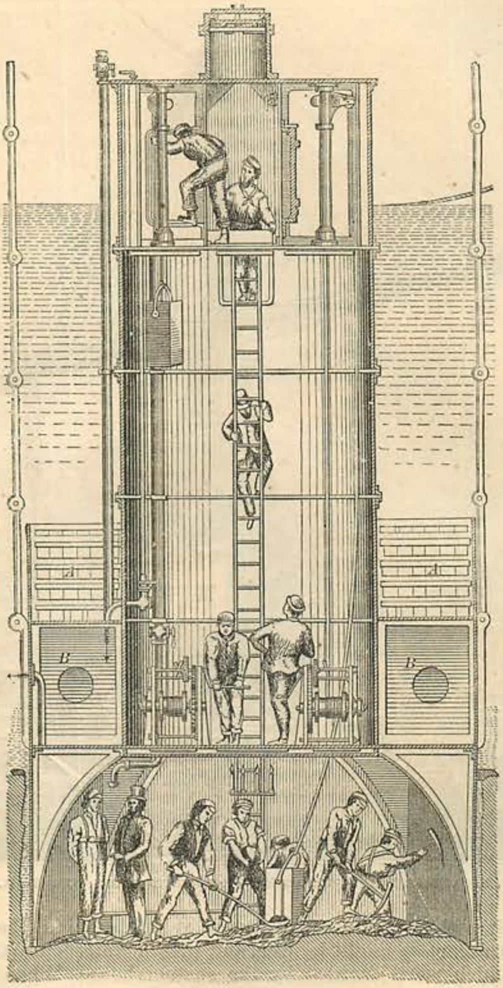
For working beneath the surface of the water we, however, have several methods unknown to the ancients, and, indeed, only used to valuable purpose within the century. The first use of the diving-bell in engineering was by Smeaton in 1779. It had been used for a century or two as a curiosity or in reclaiming sunken treasures, and had been much improved by Halley and by Spalding in 1774, before it came into Smeaton's hands.

The *pneumatic caisson*, which now forms so important an aid in sinking piers to solid foundations beneath river-beds, is the invention of M. Triger, of France, where it was first used in sinking a shaft for a coal-pit through a stratum of quicksand to reach the coal-measures in the vicinity of the river Loire, in France. It consisted of a tube made in sections, so as to be extended as the shaft deepened. The lower end was open, and divided by a floor with a tightly fitting trap-door from a middle chamber, the ceiling of which had a similar door. By means of an air-compressing pump the water was kept out of the lower chamber, where the men worked, and the buckets were handed up through the floors to the top, the middle chamber forming an air lock, which was alternately in communication with the working chamber below and with the air-chamber above it.

The figure shows a caisson used some years afterward in building the piers of a bridge at Copenhagen, Denmark. A much improved and extended plan was adopted by Captain James B. Eads in building the river piers of the Illinois and St. Louis Railway Bridge across the Mississippi; and by Colonel W. A. Roebling for the piers of the suspension-bridge across the East River, New York. In each of the last-mentioned cases the caisson is a very heavy structure, designed when it reached the solid rock to remain there, be built up full of masonry or concrete, and then support the pier which was built upon it as it descended; the Triger caisson, after its function as a pneumatic excavating chamber was completed, formed a lining for the shaft in a treacherous soil; the Copenhagen caisson was lifted as the pier built at the bottom progressed upwardly.

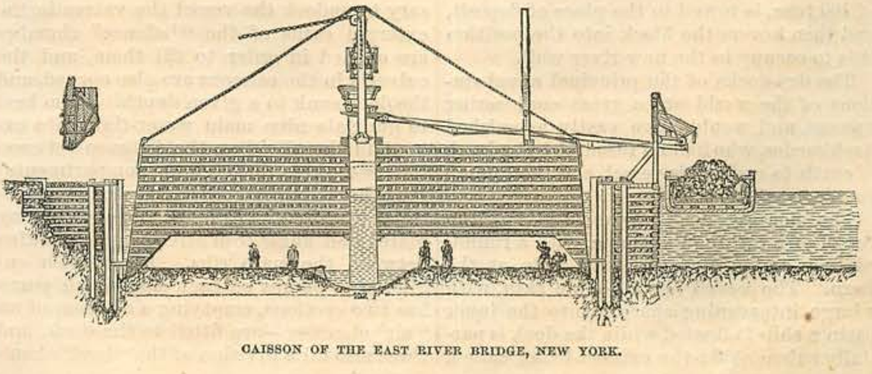
The next illustration shows an East River caisson. The mode adopted for getting rid of the excavated material in the New York caisson is the invention of M. Fleur St. Denis, chief engineer des Chemins de Fer de l'Est, in France. It consists of a water-shaft whose lower end is submerged in water in a basin, and which is traversed by a dredging bucket or grapple, according as mud or rock has to be raised. The condensed air in the other part of the interior of the caisson keeps water excluded, and makes it habitable for the workmen.

In the St. Louis caisson the sand, mud, and stones as large as a hickory-nut were driven out of the collecting basin in the floor of the working chamber by means of a powerful jet of air which lifted a column of water in a tube, and with it the finer excavated material, the pipe discharging it over the side into a lighter.

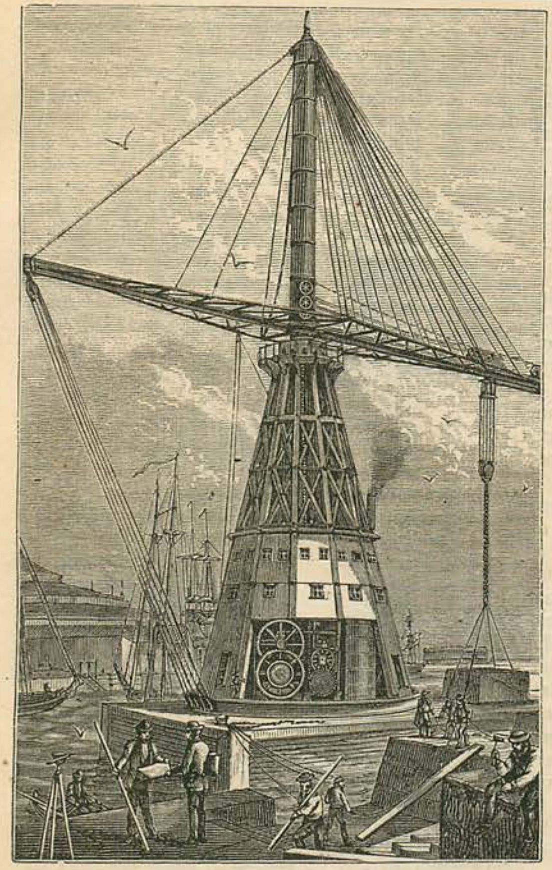


CAISSON AT COPENHAGEN.

The docks of some principal sea-ports are a marvelous feature both in character and in extent. London and Liverpool are celebrated for tidal docks. The first named had a particular object in grouping the merchantmen of special trades together in ba-



CAISSON OF THE EAST RIVER BRIDGE, NEW YORK.



FLOATING DERRICK, DEPARTMENT OF PUBLIC DOCKS, NEW YORK.

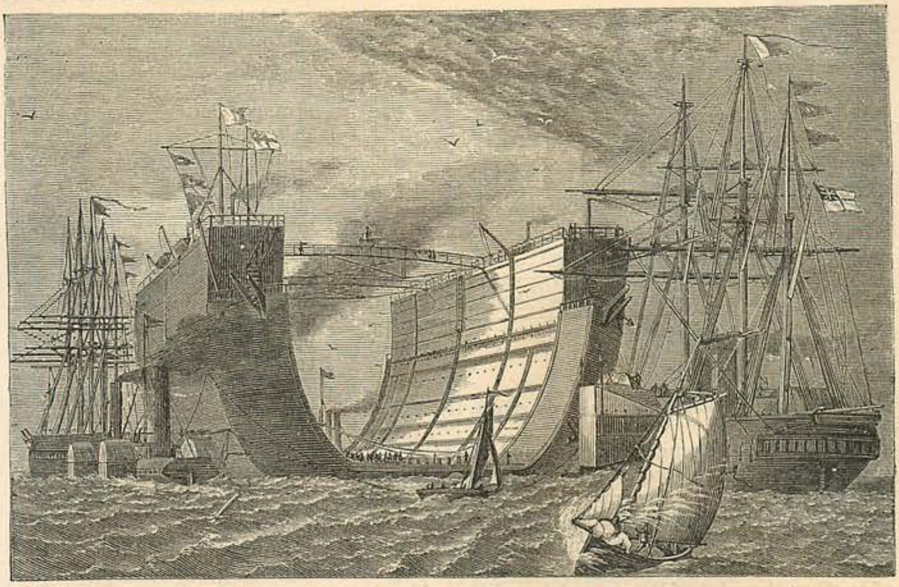
sins where the access between vessels and warehouses might be free, and within walls which were guarded by the custom-house authorities. It was also desirable to produce more wharf room. The high tides of the Mersey render the port of Liverpool very inconvenient for river and lighter work, and make tidal basins a necessity. The quays of Montreal are the best in America.

The large floating derrick of the New York Department of Public Docks picks up a block of 100 tons, is towed to the place of deposit, and then lowers the block into the position it is to occupy in the new river wall.

The dry-docks of the principal naval stations of the world are a great engineering success, and would have vastly astonished Archimedes, who had no resource but a bank of earth to embay his vessel, and then pump out the pond.

The floating dock *Bermuda* is an iron vessel of a rectangular shape, with a rounded bow and a strong caisson gate at the stern. The vessel has a double skin, with a large intervening space. Into the inner basin a ship is floated while the dock is partially submerged; the caisson being closed, the water in the dock and space intervening between the two skins is pumped out so that the interior may be dry to allow work on the vessel, and the jacket may have sufficient flotative power to carry its load.

The *Bermuda* was built in England and was towed to Bermuda by war vessels. This dock cost $1,250,000, and has the following dimensions: extreme length, 381 feet; width inside, 83 feet 9 inches; depth, 74 feet 5 inches. The weight is 8350 tons. The dock is U-shaped, and the section throughout is similar. It is built with two skins fore and aft at a distance of twenty feet apart. The space between the skins is divided by a water-tight bulkhead, running with the middle line the entire length of the dock, each half being divided into three chambers by like bulk-heads. The three chambers are respectively named "load," "balance," and "air" compartments. The first-named chamber is pumped full in eight hours when a ship is about to be docked, and the dock is thus sunk below the level of the horizontal bulkheads which divide the other two chambers. Water sufficient to sink the structure low enough to permit a vessel to enter is forced into the balance chambers by means of valves in the external skin. The vessel having floated in, the next operation is to place and secure the end caissons, which act as gates. When the water is ejected from the "load" chamber, the dock with the vessel in it rises, the water in the dock being allowed to decrease by opening the sluices in the caissons. The dock is trimmed by letting the water out of the "balance" chamber into the structure itself. The inside of the dock is cleared of water by valves in the skin, and it is left to dry. When it becomes necessary to undock the vessel the valves in the external skins of the "balance" chamber are opened in order to fill them, and the culverts in the caissons are also opened, and the dock sunk to a given depth. From keel to gunwale nine main water-tight ribs extend, further dividing the distance between the two skins into eight compartments; thus there are altogether forty-eight water-tight divisions. Frames made of strong plates and angle-iron strengthen the skins between the main ribs. Four steam engines and pumps on each side—each pump has two suctions, emptying a division of an "air" chamber—are fitted to the dock, and these also fill a division of the "load" cham-



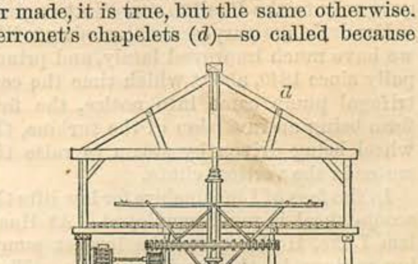
FLOATING DOCK "BERMUDA."

ber. When it becomes necessary to clean, paint, or repair the bottom of the dock, it is careened by the weight of water in the "load" chambers of one side, and the middle line is raised about five feet out of water. The *Royal Alfred*, bearing the flag of the admiral on the station, and weighing 6000 tons, was lifted by this dock, her keel resting on a central line of blocks arranged on the floor of the dock, the ship being shored up with timbers all around the top sides.

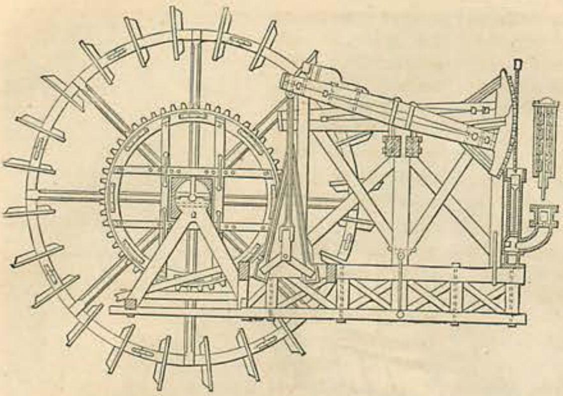
Steam-pumps are important among the engineering devices of the day. The necessity of pumping water from mines, from ponds in draining, or from sunken vessels, coffer-dams, or wet excavations, has given great importance to that special application of the steam-engine.

The Cornish engine has already been referred to, but there is a host of machines for use on shipboard, for wrecking, at railway watering stations, and used by manufacturers who require water in large quantity.

Perronet was the greatest engineer of his time, the builder of the famous bridge of Neuilly, and many other structures in France, the finest of their day, some of which yet remain witnesses to his skill and perfect taste. It is understood that his masterpiece, the bridge of Neuilly, was partially destroyed by the French during the German invasion, to render it impassable to the enemy. This was the first *level* bridge. The Waterloo Bridge, by Rennie, is even a more magnificent example. This is mentioned to introduce the fact that the chief engineer of the *ponts et chaussées* in the reign of Louis XVI. had no better contrivance for pumping out his coffer-dams than a chain-pump—the old *noria*, the *na úra* of the Arabs, "the wheel broken at the cistern" of Eccles., xii. 6. Better made, it is true, but the same otherwise. Perronet's chapelets (*d*)—so called because



PERRONET'S CHAPELETS (CHAIN-PUMPS) AT ORLEANS, FRANCE.



CURRENT WATER-WHEEL, LONDON BRIDGE, 1731.

the buckets were strung along on a band like the beads of a rosary—were worked by horse-power at Orleans, twelve at a time being employed, making 140 revolutions per hour. The pallets acted as buckets, and passed at the rate of 9600 per hour. *e* and *f* are views of another chapelet of Perronet, driven by a water-wheel in the stream outside the coffer-dam. The current water-wheels used for raising water for the city of London, 1731, were under the arches of London Bridge, and gave way to the Boulton and Watt engine.

For drainage purposes with moderate lifts we have much improved lately, and principally since 1840, about which time the centrifugal pump came into notice, the first form being an inversion of the turbine, the wheel being driven by steam to raise the water in the vertical chute.

In the fens of Lincolnshire for low lifts the scoop-wheel is much employed. At Haarlem Lake, Holland, are the largest pumping-engines in the world, perhaps. They are three in number, have annular cylinders of twelve feet diameter, with inner cylinders of seven feet diameter. One engine works eleven pumps, and the others eight each. Each engine lifts sixty-six tons of water per stroke to a height of ten feet; when pressed each lifts 109 tons per stroke to that height. Running economically, each lifts 75,000,000 pounds of water one foot high for ninety-four pounds of Welsh coal. The net effective force of each is 350 horses; the consumption of fuel is two and a quarter pounds per horse-power per hour. The surface drained by the three engines is 45,230 acres, an average lift of the water, depending on the state of the tides, being sixteen feet. All other drainage enterprises sink into insignificance beside those of Holland. They include an area of 223,062 acres drained by mechanical means.

Prominent among the engineering enterprises of the day are the tunneling of mountain chains and the removal, by drilling and blasting, of submarine obstructions.

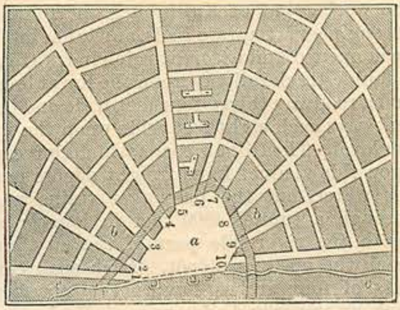
It is just about 250 years since gunpowder was first used in blasting by the German miners in Hungary; now it seems strange that any great enterprise in rock should be attempted without it. The patient labor of the men who chiseled their way through a mile of rock near Vicovaro in making the second Roman aqueduct, the Anio Vetus, is rather sad than exhilarating when we consider the unpaid labor of the poor slaves who hewed out the tunnel.

Two vast jobs of tunneling ranges of mountains have lately been completed—the Mont Cenis and the Hoosac tunnels. Another, larger one is in progress—the St. Gothard. In each case the work was done, or is being done, by drills operated by compressed-air engines, the escaping air at the workings being an element of great value, as it provides fresh air at that point and establishes an outward current.

This whole business of exhausting air, compressing air, and using the comparative vacuum or the positive pressure, is very new. It is true, Otto Guericke had an air-pump in 1650, and Samuel Pepys says, February 15, 1665, of his visit to the Royal Society at Gresham College, "It is a most acceptable thing to hear their discourse and to see their experiments; which were this day on fire, and how it goes out in a place where the ayre is not free, and sooner out where the ayre is exhausted, which they showed by an engine on purpose."

These were but chamber experiments, and air used in an engine can not probably be traced back of Glazebrook's English patent of 1797, which had the principal features of the modern approved forms. Stirling's engine, 1827, was used at the Dundee Foundry, Scotland, for some years. Medhurst patented in 1799 the device of condensing air to be used at the workings into reservoirs at the bottom of the shaft by engines at the surface. Bompas had an air-driven carriage in 1828. The rock-drills at the Bardonneche end of the Mont Cenis tunnel were driven by air compressed by a curious apparatus devised by Sommeilleur, the volume of air compressed daily being 826,020 cubic feet, giving 137,670 feet at the drills under a pressure of six atmospheres. Air-pumps condensed the air at the French end of the tunnel.

Air, steam, and gunpowder are working hand in hand through the mountains and under the water. Now 18,500 pounds of gunpowder in three charges, simultaneously fired, tear at one crash 400,000 tons of chalk from the face of Round Down Cliff,



HEADING OF THE EXCAVATION, HALLETT'S POINT REEF, EAST RIVER, NEW YORK.*

near Dover; now twenty-three tons of powder in kegs heave the roof from the previously excavated cavern 50 by 140 feet beneath the Blossom Rock in the harbor of San Francisco. Jumper drills have long been pegging away at the works in the East River, where dangerous rocks and reefs are being removed to a safe depth, or cut away to improve the approaches or prevent dangerous currents and eddies. The works at Hallett's Point are among the most important of these, and here the headings are driven radiating like the sticks of a fan, and are joined by cross galleries which leave square pillars to support the rock ceiling on which the sea beats. The galleries are numbered, and embouch into a common area (*a*), whence the excavated material is lifted by cranes; *c* is the shore line. The roof will come off some day with a bang, and the fragments will fall into the pit, and may be removed thence by grappling.

Closely allied to this work is that of boring Artesian and oil wells. These also seem to belong to us of "the latter days," although it has always been the case that wells dug in some strata become Artesian. If the source of supply be high enough, they run over, as at Artois, from whence they are named.

If the Chinese of the province On-Tong-Kias did really bore the flowing wells to a depth of from 1500 to 1800 feet, we must admit that we have but few to exceed that depth. London's Trafalgar Square wells are only 393 feet; they soon reach water seams in the chalk. The well at Calais, France, is 1138 feet; Donchery, Ardennes, 1215 feet; Grenelle, 1802; Passy, 1913; brine well at Kissingen, 2000; Belcher's sugar refinery, St. Louis, 2197. The Columbus, Ohio, 2700 feet, and St. Louis County Farm, 3235 feet, are failures as Artesian wells.

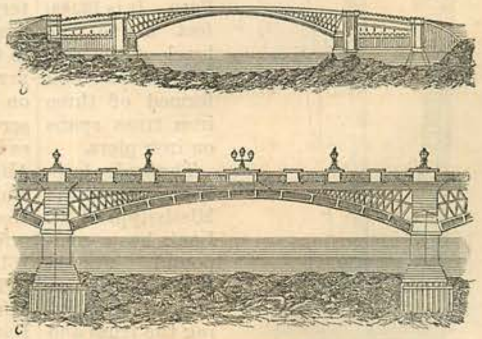
Iron has entered largely into modern structures, and the time seems near at hand when important buildings will be made of brick, iron, and cement. Sir Joseph Paxton made a long step ahead in 1851, when he constructed of iron the building to which England invited the representatives of all nations. The constructors of iron houses in our cities must abandon the attempt to imitate in iron the shapes which are proper to such materials as brick and stone.

The great success, so far, is in roofs. Those of the Grand Central Railway Dépôt, Forty-second Street, New York, and the St. Pancras Station of the Midland Counties Railway, England, are eminent instances. The former was constructed by Buckhout, and is 652 feet long, 199 feet 2 inches between walls. It covers about three acres. The St. Pancras Station has a span of 240 feet, a length of 690 feet, covering five platforms, ten lines of rails, and a cab stand twenty-five feet wide.

The use of iron in structures marks the work of the century. Engineers have in their adaptation of the new material contrived a new set of forms and parts, and made an entirely new set of calculations. The genius and skill were not wanting before, we may say, but the previous century had not the iron in quantity.

Bridge-building affords a remarkable group of structures in iron. There are four forms, the *arch*, *truss*, *suspension*, *tubular*. The projects become more and more bold.

The first iron bridge was one of cast-iron



IRON ARCH BRIDGES.

a is a representation of the cast-iron arch bridge of 600 feet span projected by Telford for crossing the Thames. *b* was a bridge of cast-iron sections, 500 feet span, proposed by Telford for the Menai Straits in preference to the suspension-bridge of 570 feet span decided upon by the committee. *c*, the middle arch of Southwark Bridge, 240 feet span.

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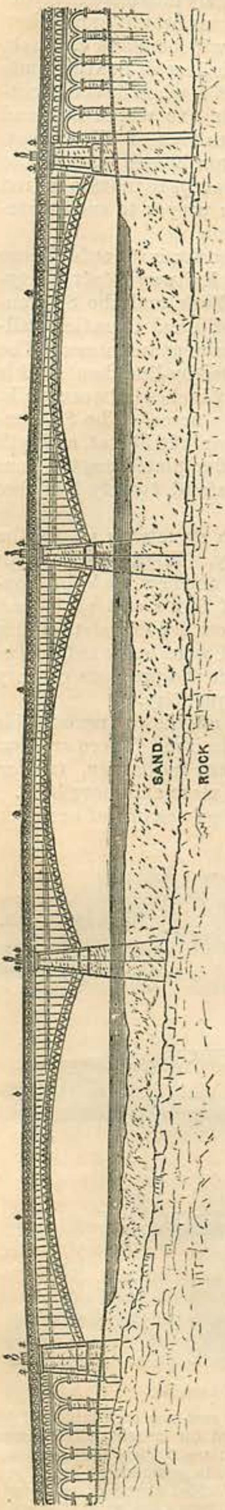
* Most of the illustrations for this article, from page 221 to page 230, are borrowed from *Knight's Mechanical Dictionary*, published by J. B. Ford and Co., New York.



THE ILLINOIS AND ST. LOUIS BRIDGE ACROSS THE MISSISSIPPI.

sections across the Severn at Colebrookdale, in England, erected in 1779 by Darby and Wilkinson, unless we may mention a foot chain-bridge seventy feet long across the Tees in 1741, and credit the chain-bridge in a mountain pass at Kingtong, in China. In 1796 Wilson erected an iron arch bridge 100 feet above the water over the Wear at Sunderland. In 1818–25 Telford spanned the Menai Straits by his so-called *chain-bridge.* Iron rods with coupling links form the catenary. Southwark Bridge (*c*) over the Thames is or was a structure of three arches of cast-iron voussoirs, and was erected in 1819.

The highest bridge in the world is the Verrugas Viaduct, on the Lima and Oroya Railway, in the Andes of Peru. It is 12,000 feet above the level of the sea, 575 feet long, and formed of three iron truss spans on iron piers.

The bridge lately built across the Mississippi at St. Louis has a compound system of steel tubular arches supporting the truss and road-beds. It has three spans of 497, 515, and 497 feet respectively. The middle arch has but one fellow in the world, that of Kuilinburg, in Holland. Its engineer is Captain Eads, and it has lately been opened amidst great rejoicing. It has a double-track railway upon the lower level, and a roadway thirty-four feet wide and two footways each eight feet wide upon the upper level. The Illinois roads which converge upon this viaduct have freight dépôts near the water, but the passenger trains pass through a tunnel 4800 feet in length beneath the river-side part of the city, and reach the up-town dépôt. Each span consists of four arches, having two members each, an upper and a lower one. Each member is of two parallel cast-steel tubes nine inches in exterior diameter set closely together, and each made in four segments, whose junctions form ribs. The upper and lower members are eight feet apart. The whole structure is stiffened by systems of diagonal, vertical, and horizontal braces.

The arch formed a very important member of many wooden bridges, and still does of some iron trusses.

Another tubular arch bridge is that of the Washington Aqueduct across Rock Creek, erected by General Meigs. It has a span of 200 feet and a rise of twenty feet, and consists of two ribs, each composed of seventeen cast-iron pipes, flanged and bolted together. The pipes are lined with staves to prevent freezing, and have a clear water way of three feet six inches. Through them passes the water for the supply of the city of Washington.

The Fairmount Bridge across the Schuylkill is 100 feet wide, was built by the Phœnixville Bridge Company, and is the finest example of an iron truss bridge in this country.

Those Chinese prevent many a broad and full statement by having anticipated the Western barbarians in so many things: gunpowder, the mariner's compass, movable-type printing, paper of rags, glazing of pottery, silk, and boring for gas and brine. Suspension-bridges also have been long used in China and Thibet. One noticed by Turner, near Tchin-Chien, was 140 feet long, on four catenary chains; one in Quito, observed by Humboldt, was of rope four inches in diameter, made of agave fibre; one in Aligpore, in Hindostan, is 130 feet in length, and made of cane with iron fastenings; Hooker notices several in Nepaul; Scamozzi refers to suspension-bridges in Europe in 1615.

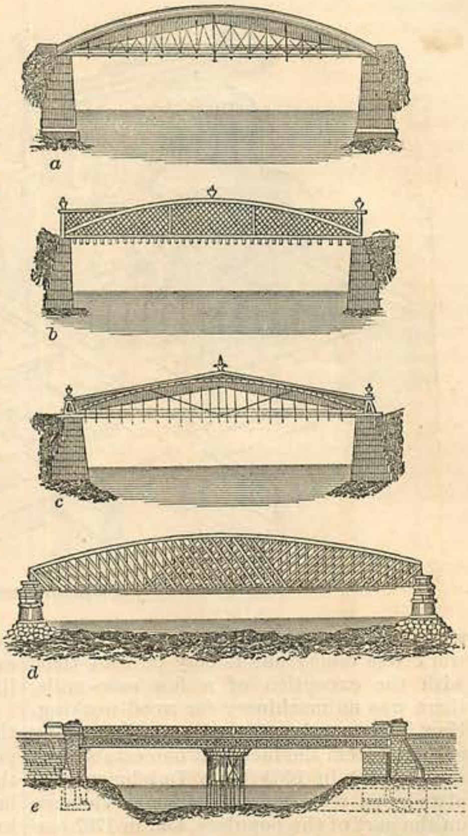
The suspension-bridge was waiting for iron. The first iron suspension-bridge in Europe, possibly in the world, was a chain-bridge across the Tees in 1741. Telford threw one across the Menai Straits, 570 feet, in 1820; it is of rods with coupling links. The Fribourg Bridge, 880 feet, was erected in 1830. The Niagara Railway Bridge, 821 feet, was erected by Roebling, 1855. The

Wheeling Bridge, across the Ohio, 1010 feet, erected by Ellet, was blown down. The Cincinnati Bridge, across the Ohio, was constructed by Roebling in 1866. It is 1057 feet between piers; each cable has 5180 wires, each laid with a given strain to bear its part of the load. This was a grand conception. The weight of wire is 1,050,183 pounds. The new Niagara Bridge, just below the basin of the falls, is 1264 feet span, 190 feet above the water, and was erected in 1869.

We are now waiting for the completion of the New York and Brooklyn Bridge, 5862 feet between termini, 1600 feet between river piers, and 80 feet wide.

The tubular bridge erected at Conway, Wales, preceded that over the Menai Straits. Succeeding them is the Victoria Bridge across the St. Lawrence River at Montreal. The principle of all is the same: a tube of rectangular section forming a hollow girder. The material is cast and wrought iron, so disposed as to secure the valuable features of each kind. It was demanded that trains should be permitted to cross each way simultaneously at full speed on the two tracks; that it should be 100 feet above the water; that no centring should be used to temporarily obstruct navigation. Stephenson made the first estimates, and Fairbairn brought into use his great knowledge in the strength of materials and skill in the disposition of parts to bear strains to which different portions of a structure are subjected. The tubes are respectively 260, 472, 472, and 260 feet, the larger ones weighing about 4,032,000 pounds each. The tubes were built on floats, towed to their positions, raised by powerful hydrostatic jacks, the masonry being built beneath them as the lifting proceeded. The jacks rested on beams on the ledges of the towers. The lifting chains weighed 224,000 pounds each, and were of six-feet sections, which were taken out, a section at a time, after each lift was made, and the tube rested on the masonry beneath it while the piston of the jack descended ready for another lift. The pressure of the water beneath the ram was 2½ tons per square inch. The tubes were lifted 100 feet above tide-water, ascending in high perpendicular grooves in the faces of the towers, which were closed up by masonry as the lifting proceeded. It was opened for traffic in 1850.

The Victoria Bridge at Montreal had no such extremely heavy work. It is 176 feet less than two miles long, having twenty-five spans, the centre one 330 feet, the others each 240 feet long. The centre span is 60 feet above the summer level of the water, and has a slight descent toward each end. The cost was £1,250,000.



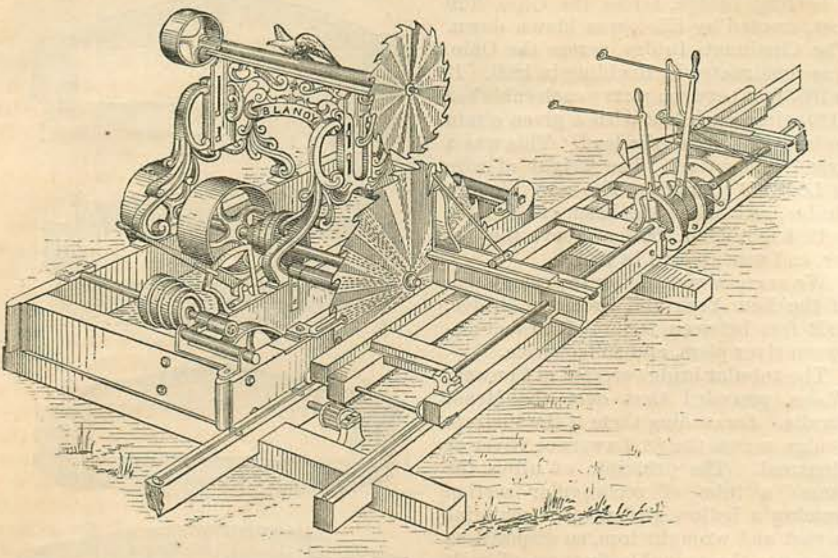
IRON TRUSS AND LATTICE BRIDGES.

a, *b*, *c*, are forms of trusses for moderate spans. *a*, rectangular-tube bridge. *b*, iron arch and lattice girder bridge. *c*, strut girder bridge. *d*, the principal span of the Kuilinburg Railway bridge over the Leck, a branch of the Rhine. It has nine spans; the one shown is 515 feet total length, 492 feet clear span. Its only rival in length is the middle span of Captain Eads's bridge across the Mississippi at St. Louis. *e* is a truss bridge over the Avon in England, the mid length resting on a cluster of screw piles.

But one of the bridges mentioned above was standing when the old bell of the red brick house in Philadelphia rang out, "Proclaim liberty throughout the land and to all the inhabitants thereof!" The solitary exception was the chain-bridge across the Tees. This bridge has long since passed away, was but a solitary precursor of the coming age of iron bridges, and in mode of structure chains have given way to wire, first of iron, then of steel.

WOOD-WORKING.

In no department of mechanical progress has the advancement been more thorough than in the machinery for the working of wood. Up to the beginning of the last quarter of the eighteenth century what were the tools and modes of the wood-worker? With the axe, adze, pit-saw, whip-



PORTABLE CIRCULAR SAW.

saw, handsaw, chisel, and rasp excellent work was done; but it may be said that, with the exception of a few saw-mills, there was no machinery for wood-working. How infrequent were the saw-mills may be gathered from the fact that one established in England in 1663 by a Dutchman was abandoned from fear of personal violence on the part of the populace, and in 1767 one at Limehouse, in the eastern part of London, was destroyed by a mob of sawyers who considered their craft in danger.

The writer distinctly recollects when logs and tree trunks were habitually sawed from end to end, to work them into dimension stuff, by two sawyers, one standing on the log and the other in a pit beneath with a veil over his eyes to keep out the sawdust. And what a hard-working, sad, drunken set these sawyers were, and how the top-sawyer bossed the wretch in the hole, who pulled down, while he above, with shoulders like an Atlas, swung his weight upon the handles above! This lasted well into our century; but now we have a host of saw-mills of various kinds working on the most extensive scale at the great lumbering centres, and machines for special work in all cities where the stuff thus roughly "got out" into square stuff or merchantable lumber is sawed into plank, dimension lumber, slats, scale-boards, veneers, and what not.

The circular saw was introduced into England in 1790, but its inventor is not known. General Sir Samuel Bentham, the most renowned of all inventors of wood-working machinery, and to whom we shall have to refer several times, patented in 1793 the bench, slit, parallel guide, and sliding bevel guide. The machine has now attained an excellence and completeness which leave little to be desired.

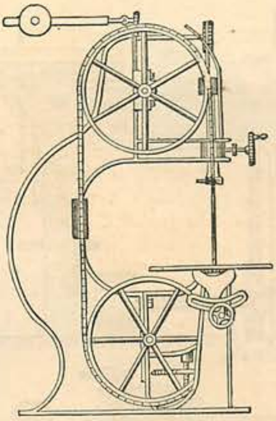
In the stationary form of the machine the saws are either single or in gangs. The portable kind has an upper saw to complete the kerf made only partially through the larger logs by the lower saw. Such is known as a *double saw*. The log carriage travels on ways, the feed being by a pinion meshing into a rack beneath the carriage.

After the cut the head-blocks are simultaneously moved up, bringing the log a distance nearer to the saw equal to the thickness of the board desired, plus the width of the kerf made by the saw. Very rapid and handy are these saws, but the men of '76 never dreamed of such a thing. We had rude gate saws driven by flutter wheels, or geared up for motion from a larger wheel. There was then no premonition of the saw-mills which hum in all our ports and buzz in all the forests of the land.

The veneer saw, a peculiar adaptation of the circular saw, with thin segmental teeth on a thin hub of large diameter, was invented by Bramah.

Nor must we forget the scroll-saw, also named a jig saw from its rapid vertical motion. It has a narrow thin blade which eats its way in a wonderful manner through the stuff which is moved against it, sliding on the surface of a flat table through which the saw reciprocates. The band saw is for the same purpose, but is a steel ribbon with a serrated edge, and runs on two band wheels, one of which is driven by the steam-power.

The planing-machine for wood assumed



BAND SAW.

three shapes before it settled into its present preferred form; indeed, there are yet two kinds. General Bentham's machine, patented in 1791, was like an immense plane pushed over the surface of the board. Bramah's machine, 1802, is what is called the *traverse planer*, the cutters being on the lower edge of a revolving disk, which revolves with its vertical arbor above the board, which passes beneath it. The more common and generally useful form of the planing-machine has revolving cutters on horizontal axes, which work the top of the board. By an extension of the principle another cutter may work the lower surface, and two others on vertical axes dress the edges, or square stuff may be dressed on all sides, or one or more of the cutters may have such conformation as to plane mouldings on the stuff.

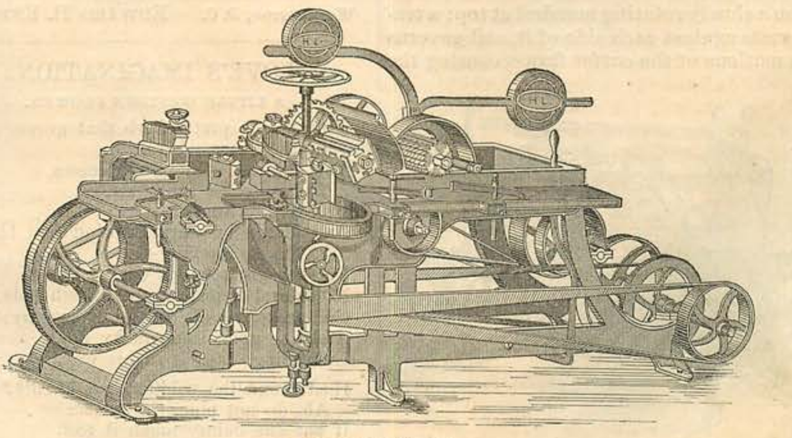
This is the moulding-machine, whose usefulness it is hard to exaggerate, but the admirable Bentham and the equally useful and perhaps equally brilliant Bramah would gaze with keen zest upon the outgrowth of their genius and pains.

Another form of moulding-machine has a vertical shaft, with cutters of the conformation required protruding through a table, so as to work the edges of the stuff brought against them, directed by the hand or by a guide.

The joiner, or *general wood-worker*, is another of the late additions to the shop. The number of years it has been in use can almost be counted on the fingers of the two hands. Though the term may not have been so intended, yet it is well placed, for it holds a very commanding rank. It planes flat, moulding, and beaded surfaces; it rips or crosscuts; it bores and counterbores; it mortises and tenons, executes squaring-up, grooving, tonguing, rabbeting, mitring, chamfering, and wedge-cutting; it is a jack-of-all-work, the handy man of the shop, with unflagging energy and singular versatility. It well represents the mature mind of the ages, being a *multum in parvo*, the combination of a set of separate machines, possessing the attributes of each, which it is ready to turn to account at any time, not always together, but in rapid succession at short notice.

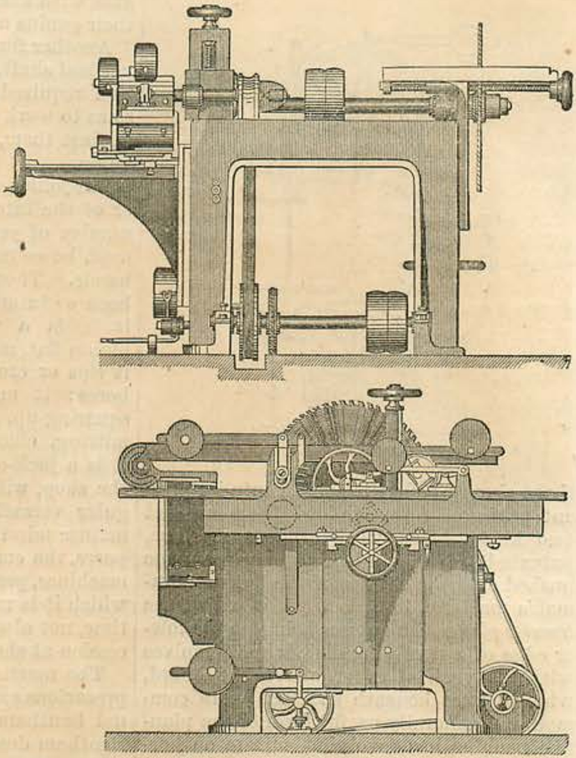
The mortising-machine may have had a precarious existence before General Sir Samuel Bentham, but we have no trace of it. Bentham describes the self-acting machine in his patent of 1793. His description includes the operation by which a hole previously bored is elongated by a chisel into a slot, and also the mode of making the mortise by a rotating cutter during the traverse of the work. He also had a pivoted table for oblique mortising, and a double or forked chisel for making narrow parallel mortises.

Brunel's machine for mortising the shells of ships' blocks was made for the British Admiralty in 1804. The block is chucked



MOULDING-MACHINE.

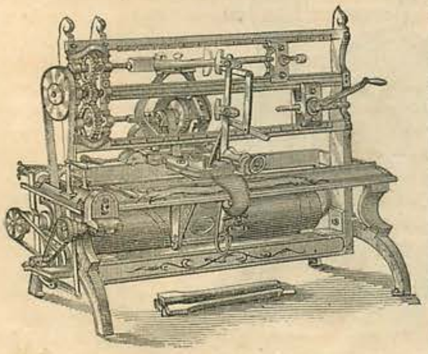
in a carriage, and has an automatic feed movement by means of a screw. The chisel (or chisels for blocks with more than one score) is in a vertically reciprocating slider in the frame above.


GENERAL WOOD-WORKER.

The latest improvements in mortising-machines have much increased their capacity and range of work, special machines being made for various duties. One principal feature is that for bringing the chisel into action and determining its depth of stroke by simply pressing upon a treadle, the chisel being quiescent as soon as the foot is lifted, and this without disconnection with the motor.

The wood-turning lathe preceded that of metal many centuries, as that for clay long preceded the wood lathe. We pass at once to the lathe for turning irregular forms, invented by Thomas Blanchard, of Boston, Massachusetts, in 1828, and since much improved by himself and others.

It is made for turning spokes, axe-handles, gunstocks, and various other crooked and difficult shapes. The illustration shows it as adapted for turning spokes. These have very different shapes at different parts of their lengths, and spokes for different kinds of vehicles require very different shapes and proportions. Like the job of standing the egg on end, suggested by Christopher Colon to his curious friends, it is very easy to understand when explained; but it was a very ingenious contrivance and a great acquisition. The model is placed upon a slowly rotating mandrel at top; a tracer rests against each side of it, and governs the motions of the cutter frame, causing the revolving cutter to advance or recede to or from the stuff which is chucked between the centres of a mandrel below, and caused to rotate in correspondence with the model above. The cutter frame has a longitudinal motion along the frame, its cutter passing from end to end of the stick, and cutting more or less deeply in exact conformity with the model above. The piece to be cut is not shown in position, as it would hide the view of the cutter head.


BLANCHARD'S SPOKE LATHE.

WASHINGTON, D. C. EDWARD H. KNIGHT.

LOVE'S IMAGINATION.

A LITTLE WESTERN FLOWER.

THERE is a pretty herb that grows
  In the every where.
The chilliest wild winter snows,
  The roughest saucy air,
  It hath a way to dare;
And kissed by warmest wind that blows,
  It blooms as fairy-fair.
Yet though it be on every side,
No mortal knows where it doth bide.
One seeks in vain till locks be gray;
And one upon some lucky day,
Unheeding, finds it in his way.

Hast found the wildling, my Lucille?
  Ah, do not pluck it, Sweet;
If but one dainty touch it feel,
  It withers at thy feet!