I.

NOTES ON FIRE-PRODUCING MACHINES. BY J. ROMILLY ALLEN, F.S.A. Scot.

It is intended in the following paper to describe and classify the machines used by man, at various periods of his history, for producing fire.

Classification of Fire-machines.—The methods of kindling fire afresh, as at present known, may be divided into four classes, namely, (1) Mechanical; (2) Optical; (3) Chemical; (4) Electrical.

The mechanical methods may again be subdivided into (*a*) Frictional, (*b*) Percussive, (*c*) Compressive.

Process of Fire-kindling.—Whatever be the means employed, the process of fire-kindling is always a triple one, consisting of the following operations:—(1) Creating a spark of fire artificially; (2) Catching the spark thus obtained in tinder; (3) Setting fire to some easily inflammable substance with the smouldering tinder.

In the case of the lucifer match these three actions are combined into one; and hence its superiority over the older and more lengthy methods.

Tinder.—As the use of tinder is involved in nearly all of the fire-kindling processes which follow it may be as well to say a few words on the subject before proceeding further. Tinder is any substance which on the application of a spark of fire smoulders, but does not burst out into flame.

Burnt linen rags were formerly used for the purpose in this country. The following substances, however, do equally well, viz., *Amadou* or German tinder. Touchpaper or porous paper which has been dipped in a solution of saltpetre, and afterwards dried. Touchwood or woody tissue in a certain stage of decay,—shreds of frayed wood,—fragments of pith, fibres of cotton, dry moss, &c.

Amongst the flora of the Swiss Lake-dwellings found at Robenhausen was the common tinder fungus (*Polyporus igniarius*).[1]

The Iroquois Indians of North America use a species of fungus which grows on the maple, or when this cannot be obtained a fungus of inferior quality found on the birch.[2]

"The Australians obtain fire by rubbing two bits of wood. In damp weather great care is taken to prevent the fire going out; for this reason they often carry a cone of *Banksia*, which burns slowly like *Amadou*."[3]

Mechanical Methods of producing Fire.—The mechanical methods for producing fire are based upon the fact that whenever motion is apparently destroyed by friction or otherwise, it is in reality simply transformed into heat or energy in another shape. This transformation of work into heat takes place when two substances are either rubbed or struck against each other, or when an elastic body such as air is suddenly compressed. Hence the division of the mechanical methods of producing fire into the three classes before mentioned, namely, (1) Frictional, (2) Percussive, (3) Compressive.

Frictional Methods.—The frictional method of producing fire consists in rubbing two substances together until sufficient heat is generated to cause a spark. The substance universally used for the purpose is dry soft wood such as deal or cedar.

The operation of rubbing two pieces of wood together for fire-making is performed in several different ways, either by a reciprocating up and down

[1] Flint Chips, p. 162.
[2] Wilson's "Prehistoric Man," vol. i. p. 132.
[3] Lubbock's "Prehistoric Man," vol. i. p. 194.

movement or by a rotary motion. The various forms of apparatus used amongst savages will now be described.

Stick and Groove Machine.—One of the simplest fire machines involving an up and down movement is what Dr Tylor terms the "stick-and-groove."[1] It consists of two parts, a long flat piece of wood and a blunt pointed stick. The former is placed on the ground and kept firm whilst the latter is held with both hands in a slanting position and rubbed violently backwards and forwards in a groove which it soon forms for itself in the lower piece, a downward pressure being kept up the whole time. The action is like that of a workman sharpening a chisel on a stone. The heat thus developed soon chars the lower wood and creates sparks, which are caught in tinder in the usual way. Dr Darwin says that the very light wood of the *Hibiscus tiliaceus* was alone used for this purpose in Tahiti. A native would produce fire with it in a few seconds; he himself found it very hard work, but at length succeeded. This stick and groove process has been repeatedly described in the South Sea Islands, namely in Tahiti, New Zealand, the Sandwich, Tonga, Samoa, and Radack groups; but he had never found it distinctly mentioned out of this region of the world.[2]

Looked on from a purely mechanical point of view, the "stick and groove" is simply a reciprocating or up and down motion in a straight line, like that of a jack-plane or hand saw, and it does not appear that any improved form was introduced subsequently as in the case of the fire-machines involving a rotary movement.

It is said that fire can be produced by sawing one piece of wood across another. The Rev. Dr M'Lauchlan says that his father saw "tin-egin" or need-fire produced in this way in the Highlands of Scotland. A Low-German book of 1593 speaks of the "nodfüre" that they sawed out of wood.[3]

Fire Drills.—Fire-machines worked by a rotary motion are called "fire-

[1] Tylor's "Early History of Mankind," p. 237.
[2] *Ibid.*, p. 237; Darwin in Narr., vol. iii. p. 438.
[3] Tylor's "Early History of Mankind," p. 258.

drills," because corresponding to each variety is an identical apparatus used for boring holes. Whether the drill was first invented for making fire and afterwards applied to boring processes, or *vice versa*, can never be determined. However, the fire drill is probably one of the earliest machines in which rotary motion was employed, and its gradual improvement led up to the simpler forms of turning lathes, from which the modern lathe was finally developed.

Hand Twirling.—The simplest kind of fire drill is that which is rotated by means of simple hand twirling. The machine consists of two parts—a round blunt pointed twirling stick eight or nine inches long, and a flat piece of wood.

The latter is placed on the ground and held firm with the feet or knees. The twirling stick is then held upright between the palms of the hands, with its blunt lower end resting in a slight hollow in the flat piece of wood beneath. A rapid rotary motion backwards and forwards is then imparted to the twirling stick with the palms, often shifting the hands up and then moving them down upon it so as to increase the vertical pressure, as much as possible. If the wood is dry sparks can be produced by one man working alone in a couple of minutes; but if the wood is either damp or otherwise difficult to kindle two men are required to work together, one beginning to twirl at the upper end of the stick, when his companions have nearly reached the bottom, and so on until fire comes. The process of hand twirling for producing fire is the most widely spread of all the known methods, and is found in every quarter of the globe. Captain Cook thus describes the use of the fire drill amongst the natives in Australia: "They produce fire with great facility and spread it in a wonderful manner. To produce it they take two pieces of dry soft wood: one is a stick about 8 or 9 inches long, the other piece is flat: the stick they shape into an obtuse point at one end, and pressing it upon the other, turn it nimbly by holding it between both their hands, as we do a chocolate mill, often shifting their hands up, and then moving them down upon it, to increase the pressure as much as possible. By this method they get fire in less than two minutes, and from the smallest spark they increase it with great speed and dexterity."[1]

Mr Paul Kane thus describes the process employed by the Chinooks on the Columbia River: "The fire is obtained by means of a flat piece of dry cedar, in which a hollow is cut with a channel for the ignited charcoal to run over. This piece the Indian sits on to hold it steady, while he rapidly twirls round a stick of the same wood between his hands, with the point pressed into the hollow of the flat piece. In a very short time sparks begin to fall through the channel upon finely-frayed cedar bark, placed underneath, which they soon ignite. There is a great deal of knack in doing this, but those who are used to it will light a fire in a very short time. The men usually carry these sticks about with them, as after they have been once used they produce the fire more quickly."[2]

The method of procuring fire among the Dacotahs or Sioux is thus described by Philander Prescott, an Indian interpreter:—"A piece of wood was squared or flattened so as to make it lie steadily, a small hole was commenced with the point of a stone, then another small stick was made round and tapering at one end. This end being placed in the hole, the Indian put one hand on each side of the round stick and commenced turning it as fast as possible, back and forward. Another held the wood with one hand, and a piece of punk with the other, so that when there was the least sign of fire, he was ready to touch the punk, and put it when ignited into a bunch of dry grass that had been rubbed fine in the hands."[3]

The following is an extract from "Nature," vol. xxi. p. 423, Mar. 4, 1880:—

"The savage process of producing fire by the friction of wood, so often described in books of travel, but seldom seen in this country, was performed by Farini's Zulus, at the Westminster Aquarium on Monday, in the presence of

[1] Cook's "First Voyage H.," vol. iii. p. 234, quoted in Tylor's "Early History o Mankind," p. 238.

[2] "Wanderings of an Artist among the Indians of North America," p. 188, quoted in Wilson's "Prehistoric Man," vol. i. p. 131.

[3] Quoted in Wilson's "Prehistoric Man," vol. i. p. 132.

Dr Tylor, Gen. Lane-Fox, Mr Francis Galton, Col. Goodwin Austen, and other members of the Anthropological Institute. Some straw being laid on the ground as a bed, two sticks were placed on it a few inches apart to form a support for the third stick, which was laid across them, having a deep notch cut in it to receive the blunt point of the drilling stick ; this was twirled like a chocolate muller between the palms of the hands, and when the twirler's hands reached the bottom they were either dextrously shifted to the top again, or another of the Africans squatting round took on and relieved the first. A spark was got in the charred dust in about five minutes, and was received with shouts and leaps of delight by the fire-makers, one of whom, carefully shielding it in a handful of straw, soon fanned it into a flame. These natives are physically fine specimens of the Kafir type."

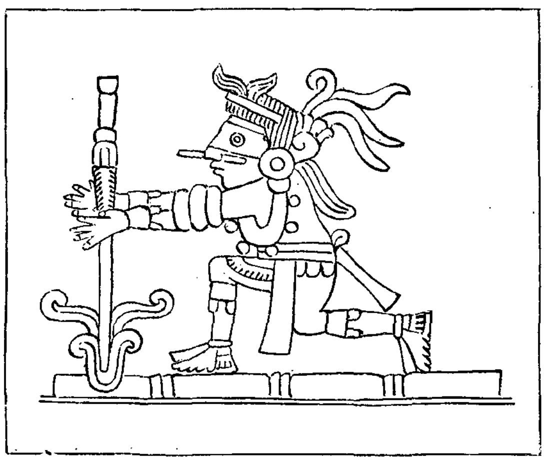


Fig. 1. Mexican representation of hand Fire Drill.

Several quaint illustrations of the use of the hand fire drill in Mexico will be found in Lord Kingsborough's magnificent reproductions of ancient Mexican picture-writing: one of them is shown on the annexed cut (fig. 1).[1]

[1] The Sanskrit name for the spindle of fire drill is "pramantha," and Prometheus, whose name was derived from it, is probably nothing more than its personification. The tube (νάρθηξ, *ferula*) with which fire was stolen from heaven, also suggests the shape of the fire stick.

Although the plan of hand twirling is such a clumsy one, it has been found in use both in South America and Madagascar for boring holes, as well as for fire making.[1]

The chief disadvantage of the hand-twirled drill is that the means of creating a downward pressure is very inefficient. This is got rid of in the improved form of fire-machine known as the cord drill.

Cord Drill.—In the cord drill the rotary motion is given by means of a cord or thong twisted once or twice round the twirling stick and pulled rapidly backwards by the hands holding both ends. The necessary downward pressure is obtained by sharpening the upper end of the twirling stick and placing over it another piece of wood, like the bottom one, held down by a second worker. The cord drill thus consists of four parts—the upper wood, the lower wood, the spindle, and the cord.

Dr Tylor quotes the following description of the use of the cord drill in India for kindling the sacrificial fire, from Stevenson's "Sama Veda," p. 7:[2]—

"The process by which fire is obtained from wood is called churning, as it resembles that by which butter in India is separated from milk. . . . It consists in drilling one piece of arani-wood into another by pulling a string tied to it with a jerk with the one hand, while the other is slackened, and so on alternately till the wood takes fire. The fire is received on cotton or flax held in the hand of an assistant Brahman." The lower wood is called in Sanscrit the "arani" and the spindle the "pramantha" or "câtra," and the sacred fire "Agni" (Lat. *ignis*). Both Kühn in his "Herabkunft des Feuers," and Emile Burnouf in his "Science des Religions" (p. 256), maintain that the well-known Swastika symbol represents the two pieces of wood composing the "arani," the ends being curved in order to be held firm by four nails.

The Indian churn referred to above consists of an upright bamboo spindle, worked with a cord, on each side of which are two forked pieces of wood tied fast to a tree so as to form bearings (see fig. 2). The bottom of the bamboo is split into four, and inserted in a jar containing the milk, thus forming a kind of whisk.

[1] Tylor's "Early History of Mankind," p. 241. [2] *Ibid.*, p. 255.

The Esquimaux of Greenland were found by Davis in 1586 using a cord drill for producing fire. The upper wood of this apparatus was furnished with a handle at each end, so that the spindle could thus be kept steady and the necessary downward pressure exerted on the lower wood by one

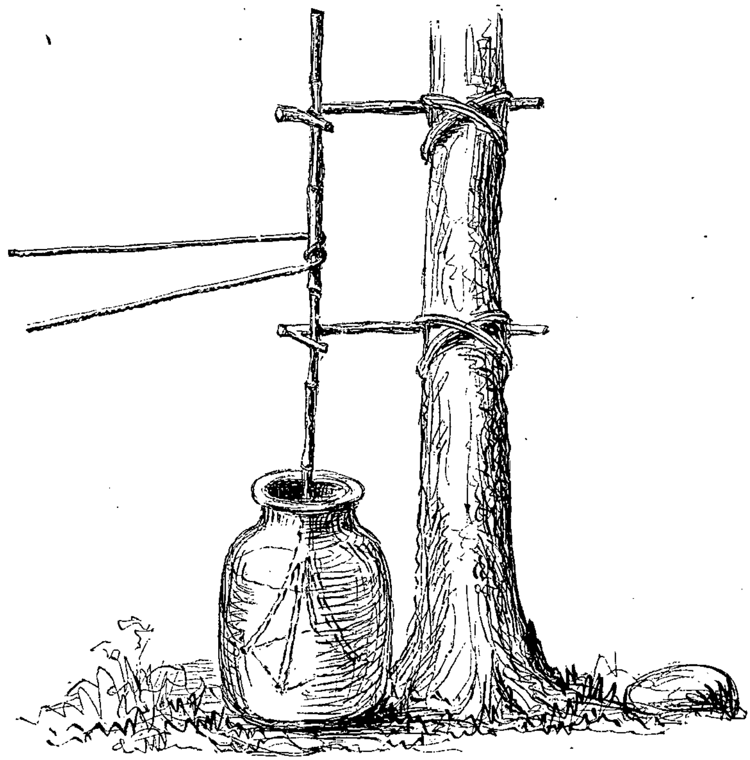


Fig. 2. Method of Churning in India.

worker whilst a second pulled violently at each end of the cord until fire came. The end of the spindle was lubricated with train oil.[1] (The Indians use butter for this purpose. See Kühn, p. 78.)

The use of the cord drill for producing fire has survived in the supersti-

[1] Tylor, p. 242; quoted from Hakluyt, vol. iii. p. 104.

tious rites of "needfire" in Germany certainly as late as the 17th century.[1] An unsuccessful attempt was made when the present paper was read to *illustrate practically the process of fire making with the cord drill.* The experiment was, however, again repeated by Mr Anderson and Mr Stevenson at the Museum in the presence of Dr Mitchell and myself, and succeeded perfectly. The following particulars may be interesting:—A piece of flat open-grained dry deal, 9 inches by $4\frac{1}{2}$ inches by 1 inch, was clamped down, to a table so as to be perfectly steady. A very shallow depression was then formed with a penknife to hold the end of the drilling stick, and a piece of touchpaper, frayed at the edge, was fastened down with a drawing pin close to it to catch the spark. The drilling stick was 9 inches long, round in section, $\frac{7}{8}$ths of an inch diameter at the lower end, and tapering slightly towards the top. The point of the lower end of drilling stick was *very blunt*, resembling in outline a flat Tudor arch, and the upper point sharp. The drilling stick was placed upright, with its lower end resting in the depression of the flat piece of wood, and its upper end rotating in a conical hole made in a round stone just large enough to hold in the hand conveniently. One person kept the drill in this position while a second worked the cord backwards and forwards as before described. The cord was 6 feet long and $\frac{3}{16}$ths thick, twisted two or three times round the spindle, and wetted so as to make it bite. A spark which lighted the touchpaper was thus produced in a quarter of a minute (timed by watch). The sparks were generated round the edge of the hole where the air had free access. Both stick and hole presented a charred appearance as if touched with a red hot poker. The point of the drilling stick must be blunt and wear a hole for itself. The depth of the hole when fire came was barely $\frac{1}{8}$th of an inch, and it seems to be much easier to get fire in a shallow hole than a deep one. The cord drill has been known in Europe since a very remote period. Homer describes Odysseus as boring out the eye of the Cyclops with a machine of this kind.[2]

[1] Tylor, p. 257; Grimm's D. M., p. 570; Jamieson's "Scottish Dictionary," articles "Neidfire" and "Black Spaul."

[2] Homer's "Odyssey," ix. 382.

In India and Central Asia the principle of the cord drill is applied to the turning-lathe. It consists simply of two pieces of wood driven into the ground so as to act as bearings for the wood to be turned, which is

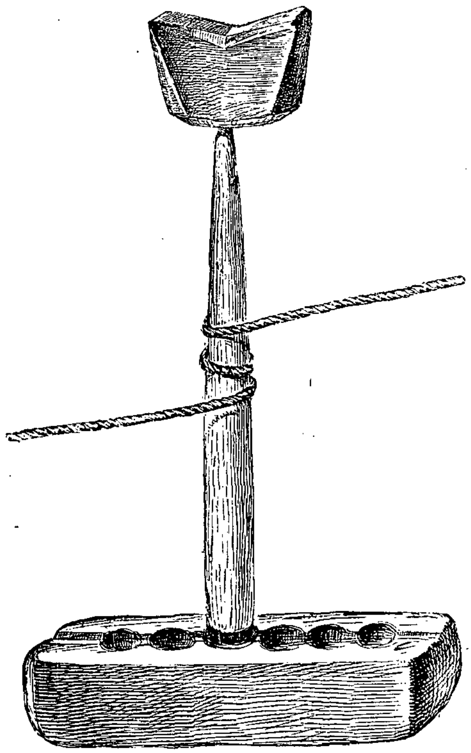


Fig. 3. Esquimaux Cord Drill and Mouthpiece.

worked alternately backwards and forwards by means of a cord twisted round it.[1] The Indian name for the cord lathe is "kharad." Sailors in England dry their mops by a similar device.

[1] Reuleaux, "Kinematics of Machinery" (Kennedy), p. 211; Holtzapffel's "Turning," vol. iv. p. 6.

Although the cord drill is a great improvement on mere hand twirling, it requires two men to work it, whereas when the wood is dry the latter only takes one.

The next step in the development of the fire machine is the getting rid of the second operator, whilst retaining the advantages of the cord drill. There are three different ways of doing this which will now be described.

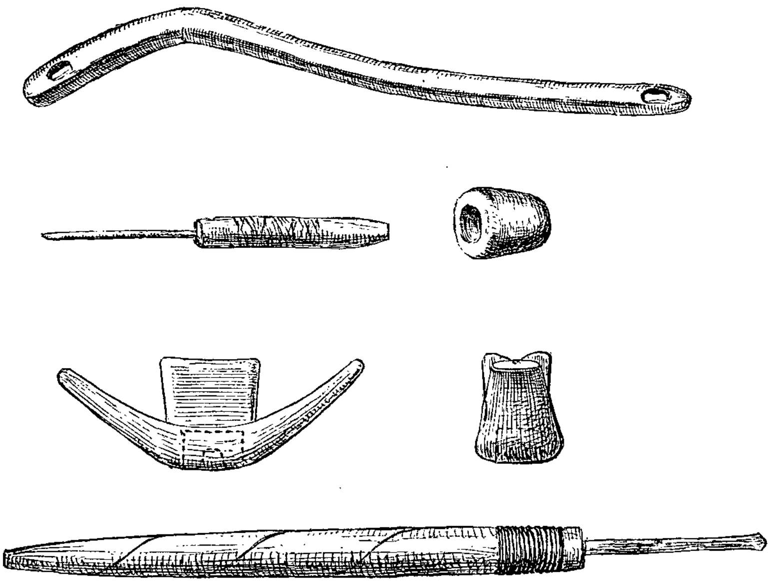


Fig. 4. Esquimaux Cord Drill Apparatus and Egyptian Bow Drill.

Cord Drill and Mouthpiece.—The cord drill and mouthpiece is the same as the simple cord drill (fig. 3), except that the upper wood is made of smaller dimensions and held between the teeth, thus leaving the two hands free to work the cord. This machine has been found in use in the Aleutian Islands both for boring holes and making fire. There is a set of the Esquimaux apparatus of this kind in the Edinburgh Industrial Museum, an illustration of which is here given (see fig. 4). Sir E. Belcher thus describes the use of the cord drill and mouthpiece for boring by means of a point of green jade :—"The thong . . . being passed twice round the drill, the upper end is steadied by a mouthpiece of wood, having a piece of the same stone imbedded, with a countersunk cavity. This held firmly between the teeth directs the tool. Any workman would be astonished at the performance of this tool on ivory; but having once tried it myself, I have found the jar or vibration on the jaws, head, and brain quite enough to prevent my repeating it." [1]

The Bow Drill.—The next way of dispensing with the second worker is by the well-known bow drill. It will be observed that in working the cord drill with outstretched arms [2] both ends of the cord are moving in the same direction at the same time. If, therefore, the near end is connected with the far end by means of a rigid bar, the cord can be worked backwards and forwards by one hand instead of two. The bow fulfils this purpose, and at the same time by its spring keeps the cord "taut." The bow drill consists of four parts—the upper and lower wood, the spindle and the bow. The method of working is as follows :—The cord of the bow is given a twist once or twice round the spindle, which is then placed vertically between the upper and lower wood. The upper wood is held with one hand, pressing the spindle hard against the lower wood, whilst the required rotary motion is given by means of the bow worked backwards and forwards with the other hand.

The bow drill is used for fire making by the Sioux Indians, and Dr Tylor gives an engraving copied from "Schoolcraft" (part 3, pl. xxviii.) of the apparatus employed by them for the purpose.[3] Dr Daniel Wilson says that the Naskapee Indians of Canada are acquainted with the bow drill for fire making.[4]

There are some quaintly-carved Esquimaux bows of walrus tusk in the

[1] Tylor, p. 243; quoted from Sir E. Belcher, in "Trans. Eth. Soc.," 1861, p. 140.

[2] The cord drill can be worked in two ways, either by "pulling the cord towards he body and then away from it, or right and left with outstretched arms."

[3] Tylor, p. 244.

[4] D. Wilson's "Prehistoric Man," vol. ii. p. 375.

British Museum (see Photos, No. 88) which are labelled as fire drills. Mr G. Goudie, F.S.A. Scot., has in his possession one of these curious bows. It is a foot long and half an inch square in section in the middle, tapering to the ends. It is perfectly rigid, and the tightening of the thong is effected by the ingenious way in which it is passed through double holes at each end. All four sides are carved, and represent hunting scenes, &c.

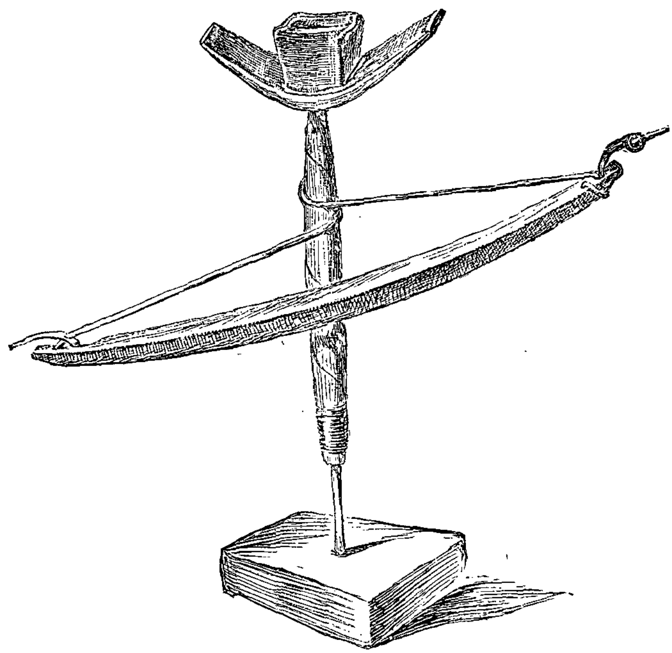


Fig. 5. Esquimaux Bow Drill.

The extraordinary resemblance between this type of Esquimaux art and that of the Palæolithic man who inhabited the caves of France has been pointed out by Sir J. Lubbock and Prof. Boyd Dawkins, in whose works engravings of some of these elaborately ornamented bows will be found.[1] There is a specimen of an Esquimaux bow drill from Fort Ander-

[1] Boyd Dawkins' "Early Man in Britain," p. 239.

son in the Edinburgh Industrial Museum (fig. 5). The bow is of bone but has a spring in it, and the spindle is of wood with a steel drill point. The upper wood is of very peculiar shape, consisting of a square block to be grasped between the finger and thumb, and having two projecting wings curving upwards on each side, like a crescent. A small stone socket is let into this piece of wood to receive the top of the drill. The bow drill has been known in Egypt from the earliest times for boring. Representations of its use occur on the walls of tombs at Thebes, and specimens found there are now in the British Museum (date 1450 B.C.).[1] The hollow socket for the top of the drill (corresponding to the upper wood in the fire drill) was made out of the nut of the Theban palm (*Crucifera thebaica*), "and being found peculiarly adapted for the purpose, from its great durability, it still continues to be used by carpenters and cabinetmakers in Egypt." The bow is of wood, and rigid: it has a rectangular hole at each end for fastening the strap. The tightening is effected by pulling the strap through the hole nearest the hand and twisting it round the crooked part of the bow which acts as a handle. The modern Egyptian bow, which is also rigid, has a "hinged piece near the handle, employed to regulate the tension of the string; the string is wrapped once or twice round the spindle, after which it is twisted round the jointed piece, which is then folded back and held in the hand with the handle."[2] The bow drill is still in use in England; the bow is a thin flat piece of steel fixed in a handle, and the tightening is managed by a pin and ratchet wheel, as in some stringed musical instruments. The drill spindle is of steel with a wooden reel upon it round which the catgut cord is twisted. The drill is worked horizontally against a breastplate, fixed on the chest. The turning lathe found all over the East is worked with a bow, and its use still survives in the watchmakers' "turn bench" in England.

The Pump Drill.—The New Zealanders use a cord drill for boring holes through hard greenstone, &c., in which the spindle itself is weighted. It

[1] Sir G. Wilkinson's "Egypt," vol. i. p. 400; Rossellini's "Egypt," vol. ii. pls. 44 and 52 given in Holtzapffel's "Turning," vol. iv. p. 3; Brit. Mus. Photos., No. 305.

[2] Holtzapffel's "Turning," vol. iv. p. 9.

is described as "a sharp wooden stick, 10 inches long, to the centre of which two stones are attached, so as to exert pressure and perform the office of fly-wheel. The requisite rotary motion is given the stick by two strings pulled alternately."[1] Perhaps the idea of weighting the spindle,

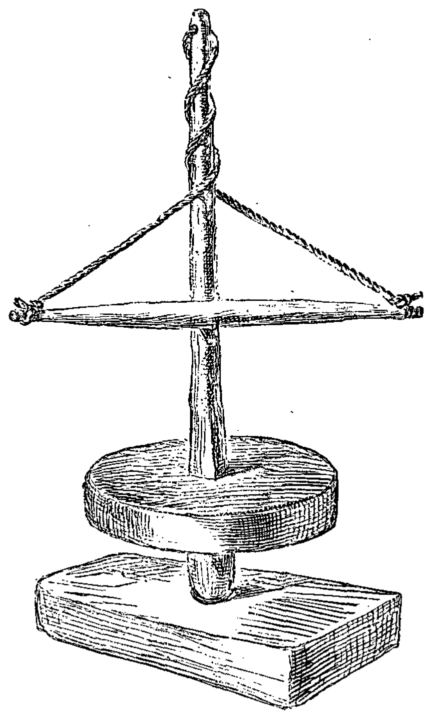


Fig. 6. Pump Drill.

together with the knowledge of the bow, may have led up to the invention of the "pump drill," which will now be described.

This instrument derives its name from the fact of its being worked up and down like a pump.

It consists of an upright wooden spindle, near the bottom of which a

[1] Tylor, p. 243; quoted from Thomson's "New Zealand," vol. i. p. 203.

heavy fly-wheel is mounted, and a horizontal cross piece, whose two ends are connected with the top of the spindle by a cord passing through a hole or notch in it (see fig. 6). The method of working the drill is as follows:—The spindle is placed vertical and twisted with one hand, thus winding the cord round it and raising the cross piece which is held with the other hand. The cross piece is then brought down suddenly, unwinding the cord and thus driving the spindle round. Whilst the cross-piece is being lifted the fly-wheel runs on and rewinds the cord in the opposite direction, so that the operation can be again repeated and kept up indefinitely.

The pump drill is described by L. H. Morgan as being used by the Iroquois Indians of North America for producing fire,[1] and is stated to be an Indian invention of great antiquity. An engraving of the machine is given in Tylor. The spindle is described as being 4 feet long and 1 inch diameter, and the cross piece a bow 3 feet long. The pump drill is used in Europe, China, and the South Sea Islands for boring holes. There is a specimen of a pump drill from Bowditch Island in the Hunterian Museum at Glasgow presented by Turner.[2] The point is of stone, and the fly-wheel a round disc of wood; the cross-piece hangs loose by the side of the spindle. Tylor gives an engraving of a Swiss drill differing from the former only in having a steel point, and in the spindle passing through a hole in the centre of the cross-piece. The pump drill used in England is the same as the last, except that it has a metal bulb for a fly-wheel. It is used chiefly by china and glass menders on account of "the lightness and evenness of its pressure lessening the danger of cracking these brittle materials." A sketch of a Chinaman using the pump drill is given in Holtzapffel's Turning.'"[3] The fly-wheel is placed on the top of the spindle instead of near the bottom, and the cross-piece hangs loose.

Centre-bit Drill.—The centre-bit drill is so well known amongst joiners of the present day that it hardly needs to be described more than to point out that it is simply the principle of the crank applied to drilling. This instrument has been found in its most primitiveform by Dr Darwin in use

[1] Tylor, p. 246; quoted from the "League of the Iroquois," p. 381.

[2] Tylor, p. 245.

[3] Vol. iv. p. 4.

amongst the Gauchos of the Pampas of South America; but, as Dr Tylor remarks, the Gauchos are not savages, but half-breeds, and this machine may have been suggested by the European tool it so closely resembles.

Dr Darwin describes its use as follows:—"Taking an elastic stick, about 18 inches long, he presses one end on his breast, and the other (which is pointed) in a hole in a piece of wood, and then rapidly turns the curved part like a carpenter's centre-bit."[1]

It will be noticed that this is the only form of fire drill in which the motion is continuous, as in all the others the movement is backwards and forwards. It also involves a standing attitude if used as described by Darwin, which is rather against its being employed except by Europeans.

Development of the Fire-drill.—Having concluded the description of most of the known ways of producing fire by means of friction, it may be worth while to consider briefly what part the fire drill has played in the general development of machinery. It should be noticed that the completeness of a machine depends on the relative parts played by human action and by the machine itself, and that machine is most perfect which involves least skill on the part of the operator. As an instance of this the cord drill requires far less skill to work it than hand twirling does, and the former is, therefore, the more highly developed machine of the two. In studying the different kinds of fire drills, it is possible to trace the gradual improvement in the means of obtaining rotary motion beginning with simple hand twirling, then the cord drill, and lastly the bow drill. It has been shown that all these methods have been applied to boring holes as well as fire raising, and that the last two are used in the turning lathe found all over the East. The Chinese employ a form of cord lathe in which the two ends of the cord are attached to treadles worked up and down alternately by the feet.[2] The earliest known European machine for turning is the pole lathe. This is a further development of the cord principle, adapted probably (as Holtzapffel points out) to the erect attitude universally chosen by the European mechanic in preference to a sitting one

[1] Tylor, p. 241; Darwin in Narr., vol. iii. p. 488.

[2] Holtzapffel's "Turning," vol. iv. p. 16.

while at work. In the pole lathe the rotary motion is obtained by means of a vertical cord attached to a treadle at the bottom, then passing once or twice round the piece of wood to be turned, and fastened at the top to the end of a springy lathe or pole, stuck out horizontally at right angles to the wall. When the treadle is depressed it pulls the cord down, causes the wood to revolve, and bends the pole down at the same time; on removing the pressure of the foot from the treadle, the spring of the pole pulls it up again, so that a fresh turn can be applied to the wood by its means. The pole lathe is still used in England for turning wooden bowls and flutes with projections for keys. It is also found in Japan, Italy and elsewhere. During the 18th century the pole lathe was gradually superseded by improved machines in which the rotary motion was continuous, and in one direction instead of backwards and forwards. This was effected by discarding the pole and substituting for it a fly-wheel and driving band. The fly-wheel was detached and placed either above at one side or below the lathe, and worked in some cases by hand and in others by a crank and treadle. The driving band was crossed and required a tightening apparatus. In the modern lathe the fly-wheel and crank form part of the machine instead of being detached; the form of treadle and crank has been improved, and the tightening apparatus for the driving band dispensed with. The crank and treadle are separate inventions by themselves, and were used in the spinning wheel long before they were applied to the lathe, but the origin of the driving band may fairly be traced back through its successive phases of development to the cord drill.

Mechanical Methods—Percussion.—In the frictional methods of producing fire, the material used is generally soft wood, and the operation is more or less lengthy, whereas in the percussive methods the substances employed are usually of a hard flinty nature, and the process almost instantaneous. In all the percussive methods two pieces of the substance are required, and these are held one in each hand and struck together violently so as to cause sparks to fly, which are caught in tinder.

Split Bamboo.—In Eastern Asia and in the Malay Islands of Sumatra and Borneo, fire is got by striking together two pieces of split bamboo:

This is rendered possible by the hard silicious coating of the cane. It would seem, however, that there is some disadvantage in the process (perhaps the liability to cut the fingers), as it has not superseded the fire drill in the localities where it is known. Sometimes the process is varied by rubbing one piece of bamboo with a sharp edge against another.[1]

Fire Stones.—The method of striking fire by means of two stones is of great antiquity. The substances possessing this property are called fire-stones, and silica (in the form of flint, quartz, or agate) and iron pyrites are the most universally used. The Greek word πυριτης means fire stone, and the term was applied to flint as well as to the mineral now known by that name. The natives of Terra del Fuego (Land of Fire) procure fire by striking together flint and iron pyrites.[2] The same method is also employed by the Slave and Dog Rib Indians of North America, by the Esquimaux, and by the Algonquin Indians. "The Alashkans are reported to obtain fire by striking together two pieces of quartz rubbed with sulphur over some dry grass or moss, strewed with feathers, where the sulphur falls."[3]

The Palæolithic cave men were probably acquainted with the use of fire stones. Iron pyrites and hæmatite strike-a-lights were found in the cave of Les Eyzies, valley of the Vézère, Périgord (see Lartet and Christy's "Reliquiæ Aquitanicæ," p. 248). M. Dupont also found iron pyrites in the Trou de Chaleux in Belgium.[4] Mr Worthington G. Smith tells me he has found traces of fire in the shape of masses of burnt wood and burnt stones in the Palæolithic sands and gravels near London, but no iron pyrites. He has also found strike-a-lights of flint and iron pyrites at Maiden Bower Camp, Bedfordshire, and of quartzite at Warren Hill, Norfolk. Professor Boyd Dawkins illustrates a flint and iron pyrites strike-a-light of the Bronze Age found together at Seven Barrows, Lambourne, Berks.[5] Dr Evans

[1] Tylor, p. 238; quoting Bowring, vol. i. p. 206; St John, vol. i. p. 137; Marsden, p. 60; Tennent, "Ceylon," vol. i. p. 105.

[2] Tylor, p. 247; Wilson's "Prehistoric Man," vol. i. p. 134; quoting Weddell's "Voyage towards the South Pole in 1822," p. 167; Wallis, 1767, Sarmiento de Gamboa, 1580.

[3] Tylor, p. 248.

[4] Boyd Dawkins' "Early Man in Britain," p. 210.

[5] *Ibid.*, p. 358.

observes that the statement of Pliny that fire was struck out of flint by Pyrodes, the son of Cilix, is a myth which points to the use of silex and pyrites rather than of steel.[1]

Flint and Steel.—In most countries where iron is known, the flint and steel process had superseded all others, before the introduction of lucifer matches. The flint and steel apparatus as used in this country at the beginning of the present century consisted of a piece of steel about $\frac{1}{4}$ of an inch thick and $\frac{1}{2}$ an inch wide and 3 inches long, bent round into the form of a hook or sometimes a ring, so as to be held conveniently between the first two fingers and thumb, a small bit of flint called a "strike-a-light" and a tinder-box.

Strike-a-lights.—The chief seat of the strike-a-light manufacture is at Brandon in Suffolk, where they still continue to be made in small quantities for exportation. Brandon was in prehistoric times one of the principal places where flint implements were made, and was, in fact, the Sheffield of the Stone Age. After the introduction of bronze and iron, the trade dwindled down into the making of strike-a-lights only, until gunpowder was invented, and the trade again revived owing to the demand for gun-flints. The earliest gun-flints were merely small strike-a-lights, and the form of the strike-a-light was in its turn derived from that of the scraper of the Stone Age. The strike-a-lights used before the introduction of metal are identical with those made at Brandon even at the present day.[2]

Tinder-box.—The tinder-box commonly used in this country fifty years ago, and even surviving in remote districts up to the present day, consists of a round tin box, 4 inches in diameter and $1\frac{1}{2}$ inch deep, with a movable lid. In the inside is a close-fitting cover, convex in the middle, and with a handle for lifting it, the use of which is to put out the tinder when done with by excluding the air. In some cases the lid of the box forms a candlestick. The operation of producing fire with the flint and steel consists in striking the steel (figs. 7 and 8) briskly against the flint, thus causing sparks to fly, which are caught in the tinder. When the

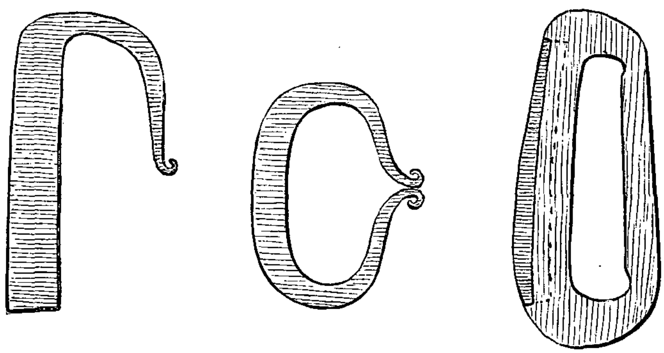
[1] Evan's "Stone Implements," p. 14.

[2] Dr Ure's "Dictionary," ed. 1878, Suppl., p. 375.

spark falls on the tinder it begins to smoulder, and a flame is obtained from it by means of a brimstone-tipped deal match, sometimes called a "spunk."

There is an Esquimaux steel (fig. 9) in the Edinburgh Industrial Museum, set in a bone handle, perhaps to avoid cold. The steel itself appears to be a bit of an old flat file.

A form of flint and steel apparatus is in use amongst smokers at the present day. The tinder is made into a small rope about $\frac{1}{4}$ of an inch diameter, and passes through a metal tube 3 inches long, out of which it is drawn by means of a small hook attached to a chain. The other end of the chain is fastened to a little plug fitting into the end of the tube, and



Figs. 7, 8, 9.

serving the same purpose as the inner cover of the tinder-box. On the top of the tube is fixed a flat bit of steel, and a bit of agate, 1 inch square and $\frac{1}{4}$ inch thick, is hung at the end of another chain. The bit of agate is struck against the steel, and ignites the tinder rope immediately beneath it. This apparatus is used by smokers because the wind does not blow out the tinder.

Mechanical Methods—Compression.—The last of the mechanical methods of producing fire to be described is that in which the required heat is generated by compressing air. The apparatus consists of a brass tube, $3\frac{1}{2}$ inches long and $\frac{3}{8}$ths of an inch diameter, closed at one end, and fitted with a piston packed in the usual way. On the top of the piston rod, and on the bottom of the tube, are two flat boxwood knobs, 1 inch in diameter. A small bit of German tinder is placed in a hollow at the end of the piston, and it is then forced down sharply to the bottom of the tube by aid of the flat knobs. The sudden compression of the air creates sufficient heat to set the tinder on fire. Dr Tylor says that an instrument on this principle, made in hard wood, ivory, &c., is used as a practical means of making fire in Burmah and also among the Malays.[1]

Optical Methods—The Burning Mirror.—There are two optical methods of producing fire by means of the heat of the sun's rays, which are concentrated or brought to a focus either by reflection or refraction. Firstly, there is the burning mirror.

The surface of the burning mirror must be concave and of a highly polished material which will reflect rays of heat. The best form is a paraboloid, but a flat spherical one which gives a good caustic will answer almost as well. In order to obtain fire with the burning mirror, it must be placed facing the sun and the tinder in the focus. Tylor says that he has lighted brown paper in England with a parabolic mirror only 2 inches in diameter.[2] This instrument was certainly known in Pliny's time (A.D. 23–79), as he mentions its power of burning (Pliny, ii. 111), and probably even earlier. Tylor mentions the discovery of concave mirrors of iron pyrites in the ancient Peruvian tombs, but discredits Garcilaso de la Vega's story of their being used for kindling the sacred fire. The Chinese are acquainted with the burning mirror, their name for it being "Kin-suy."

Optical Methods—The Burning Lens.—The principle of the burning lens is the same as that of the burning mirror, except that the rays of heat are refracted instead of being reflected. It must be made of a substance through which rays of heat can pass readily, and its surface must be convex or spherical. The use of the burning lens for producing fire is described in the "clouds" of Aristophanes (Aristoph., "Nubes," 757), and it must,

[1] Tylor, p. 247; quoting Bastian, "Oestl. Asien.," vol. ii. p. 418; Cameron's "Malayan India," p. 136.

[2] Tylor, p. 252.

therefore, have been known to the ancient Greeks. The Chinese use the burning lens for lighting fires, and the Siamese for obtaining the sacred fire.[1] Pliny also mentions the burning lens (xxxvi. 67, xxxvii. 10).

Chemical Methods—The Brimstone Match.—The chemical methods of producing fire have during the present century superseded all others. The various kinds of lucifer matches belong to this class. The earliest form of match was used in connection with the flint and steel, and was known as the "brimstone match." These matches consisted of thin strips of highly resinous or very dry pine wood, about 6 inches long, with pointed ends which had been dipped in melted sulphur. Thus prepared, the sulphur points could be instantly ignited by a spark struck into tinder with a flint and steel. The brimstone match was almost in universal use during the first quarter of the present century, and marks the transitional stage between the mechanical and chemical modes of obtaining fire.[2]

Chemical Methods—The Instantaneous Light Box.—The first purely chemical means of producing fire was introduced about the year 1830, and was called the "Instantaneous Light Box." It consisted of a small tin box containing a bottle filled with sulphuric acid (in which a sufficient quantity of fibrous asbestos was soaked to prevent it spilling), and a supply of properly-prepared matches. These matches were small splints, about 2 inches long, coated with a chemical mixture of the following ingredients: —chlorate of potash, 6 parts; powdered loaf sugar, 2 parts; gum arabic, 1 part—the whole coloured with a little vermillion, and made into a thin paste with water. The splints were first dipped into melted sulphur, and afterwards into the prepared paste. The light was obtained by dipping the prepared ends of the matches into the sulphuric acid. There were two strong objections to the instantaneous light box—firstly, that the sulphuric acid was dangerous, and secondly, that the matches rapidly absorbed moisture. This apparatus was, consequently, soon superseded by the lucifer match, which, though not the same as the form of match now in use, has handed down its name to it.

[1] Tylor, p. 249; quoting Davis, vol. iii. p. 51; Bastian, "Oestl. Asien.," vol. iii. p. 516.

[2] Chambers's "Encyclopedia," vol. vi. p. 363.

Chemical Methods—The Lucifer Match.—The lucifer match consisted of small strips of wood or pasteboard, tipped with sulphur, chlorate of potash, sulphuret of antimony, and gum. The process of getting a light was by drawing one of the matches through a piece of bent sandpaper. The friction caused the explosive materials to take fire, and light the sulphur-coated match beneath. Thus the explosives take the place of the fire drill or flint and steel in the older methods, and the sulphur helps to ignite the match instead of tinder. The gum in the composition is for making the chemical composition adhere to the end of the match during the operation of striking.

Chemical Methods—The Congreve Match.—The lucifer match was again superseded by the Congreve match still in use. It was tipped with phosphorus, nitrate or chlorate of potash, sulphur, gum, and colouring material. The lighting was effected by striking it on a piece of glass paper on the side of the box. A great drawback to the Congreve match when it was first introduced was the use of phosphorus, the fumes of which produce a most loathsome disease, causing the bones to decay. This difficulty was, however, got over by the introduction of an amorphous phosphorus, discovered by M. Schrötter, which answers its purpose just as well as the other, and is not injurious to health.

Chemical Methods—The Swedish Safety Match.—The last improvement is the Swedish safety match, invented by a Swede named Lundstrom, a large manufacturer of matches at Jönköping, in the year 1855 or 1856. This match has been subsequently patented in this country by Messrs Bryant and May. The peculiar advantage of the safety match is that it will light only on the box. This is effected by dividing the combustible materials between the match and the friction paper. In the ordinary lucifer match the phosphorus, sulphur, and chlorate of potash are altogether on the match, which ignites when rubbed against any rough surface; but in the safety match the chlorate of potash and sulphur is placed on the match and the phosphorus on the friction paper, so that neither match nor friction paper can take fire singly under ordinary circumstances.

Chemical Methods—The Döbereiner.—Before lucifer matches came fully into use, a chemical apparatus known in Germany as "döbereiner" was used to a considerable extent for obtaining a light. It consists of a cylindrical glass jar, 4 inches in diameter and 6 inches high, with a flat trap cover, from the centre of which hangs down a glass bell, 2 inches in diameter and 4½ inches long, reaching down almost to the bottom of the jar. Inside this bell are suspended half a dozen square pieces of zinc with holes in them, so that they can be threaded on an iron wire. On the top of the cover is a jet and stop-cock opening out of the bell, and in front of it a small chamber containing a small bit of spongy platina. The jar is filled with dilute sulphuric acid, which, acting on the zinc, generates hydrogen gas. When the gas is allowed to play upon the platina it renders it incandescent, and a light can be obtained by applying a spill.

Electric Methods—The Electric Spark.—Fire can be obtained anew by means of the electric spark, which is caused by the increased resistance offered to the passage of a current of electricity passing between the opposite poles of a battery, when there is a small gap in the wire conveying the current. Several attempts have been made to utilise electricity for lighting, but it does not appear likely at present to take the place of matches for producing fire anew, so that the electric match must remain amongst the possibilities of the future.

In conclusion, it only remains for the author to acknowledge how largely he is indebted to the works of E. B. Tylor, Sir J. Lubbock, D. Wilson, to Chambers's "Encyclopedia," Dr Ure's "Dictionary," &c., for the greater part of the information contained in this paper.