CHAPTER IV.

ON THE PRINCIPLES OF THE ACTION OF CUTTING TOOLS.

476. **General Explanations.**—In making the bearing and working surfaces of the parts of a machine, it is only a rough approximation to the required figure that can be obtained by casting, by forging, or by pressure. The precision of form which is essential to smooth motion and efficient working is given by means of cutting tools. The object of the present chapter is to give a brief statement of the principles upon which the action of such tools depends. For detailed information respecting them, reference may be made to the second volume of Holtzapffel's *Treatise on Mechanical Manipulation*, extending from page 457 to page 1025, and to Mr. Northcott's *Treatise on Lathes and Turning;* and for a very clear summary account of their nature and use, to an Essay by Mr. James Nasmyth, published at the end of the later editions of Buchanan's *Treatise on Millwork.*

The appendix to Holtzapffel's volume contains two essays of much value on the general principles of cutting tools—one by Mr. Babbage, and the other by Professor Willis.

477. **Characteristics of Cutting Tools in General.**—The usual material for cutting tools is steel, of a degree of hardness suited to that of the material to be cut. Every cutting tool has at least one cutting edge; and sometimes three or more edges meet and form a point, two or more of those edges being cutting edges; so that the form of the cutting part of a tool is that of a wedge, or of a pyramid, as the case may be. A cutting edge is formed by the meeting of two surfaces, generally plane, and sometimes curved. When a surface forming a cutting edge is oblique to the original surfaces of the bar out of which the tool is made, that surface is called a *chamfer* or *bevel.* The angle at which those surfaces meet may be called the *cutting angle.* It ranges from about 15° to 135°, according to the nature of the material to be cut, and the way in which the tool is to act upon it. Examples of cutting angles of tools for different purposes will be mentioned further on. A narrow cutting edge at the end of a bar-shaped tool is often called the *point* of the tool; the body of the tool is called the *shaft* or the *blade;* the term *shaft* being usually applied to tools with a cutting point or narrow edge at one end, and *blade* to those which have a longitudinal cutting edge; but *blade* is often applied to

both kinds of tools. A bar-shaped shaft is sometimes called a *stem*. The blade or shaft of a tool is sometimes made of iron, and edged or pointed with steel. A larger piece, to which the blade is fixed, is called the *stock;* and in the case of hand-tools, that part of the stock which is grasped by the hand is called the *handle*. The stocks and handles of hand-tools are usually of wood of some strong and tough kind. Where steady pressure is to be exerted, stiff woods are to be chosen, such as beech and mahogany; where blows are to be given, flexible woods, such as ash. Machine-tools are held in *tool-holders* of different sorts, made of cast and wrought iron. A *rest* is a fixed or moveable support for a cutting tool; in machine tools, the rest carries the tool-holder.

The term *machine-tool* is often applied, not merely to the cutting implement itself, but to the whole machine of which it forms part.

The piece of material which is being cut by a tool is commonly called the *work*. A given relative motion of the work and cutting tool may be obtained either by keeping the work fixed and moving the tool, or by keeping the tool fixed and moving the work, or by a combination of both those motions.

478. **Classification of Cutting Tools.**—The following classification is that of Holtzapffel. Cutting tools, according to their mode of action on the bodies to which they are applied, are divided into *Shearing*, *Paring*, and *Scraping* tools; the following being the characters by which those tools are distinguished from each other.

I. A *Shearing Tool* acts by dividing a plate or bar of the material operated on into two parts by shearing; that is to say, by making these two parts separate from each other by sliding at the surface of separation.

II. A *Paring Tool* cuts a thin layer or strip, called a *shaving*, from the surface of the work; thus producing a new surface.

III. A *Scraping Tool* scrapes away small particles from the surface of the work; thus correcting the small irregularities which may have been left by a paring tool.

479. **Shearing and Punching Tools.**—A pair of shears for cutting iron usually consists of two blades; the lower fixed, and the upper moveable in a vertical direction. The inner faces of the blades are plane, and are so fitted as to slide past each other very closely, but without appreciable friction. The ordinary angle for the cutting edges is from 75° to 80°. In shears for cutting plates, the edge of the lower blade is horizontal; that of the upper blade has an inclination of from 3° to 6°, in order that the shearing may begin at one edge of the plate, and go on gradually towards the other edge. Fig. 282 represents a cross-section of the blades of a pair of shears, with their cutting

edges at A and B, and having between them a plate or bar, C C, which is to be shorn through at the plane whose trace is the dotted line A B.

The blades of shears for cutting angle-iron bars have V-shaped edges, to suit the form of cross-section of the bars.

The class of shearing tools comprehends also tools for *punching;* the only difference being in the form of the surface at which shearing takes place; which form determines that of the cutting edges of the tools. The general principle of the action of those tools is shown in fig. 283; in which C C is a plate, lying upon the *die*, represented in vertical section by B B; that is, a flat disc or block of hard steel, having in it a hole a little larger than the hole that is to be punched in the plate. A is the *punch*, of a cylindrical figure, its base being of the size and figure of the hole to be made. The descent of the punch causes the material of the plate C C to separate by shearing at the surface whose traces are marked by dotted lines, and drives out a piece called a *wad*, which drops through the hole in the die. The wad is slightly conical; its upper end being of the size of the punch, and its lower end nearly of the size of the hole in the die.

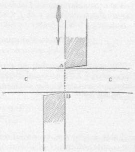

Fig. 282.

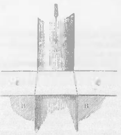

Fig. 283.

The ordinary difference of diameter between the punch and the die ranges from 0·1 to 0·3 of the thickness of the plate. Sometimes the die is made proportionately larger, in order that the holes may be more conical.

The smaller end only of a punched hole is accurate in size and figure, and smooth. The larger end is more or less irregular and ragged. When it is necessary that a punched hole should be made regular and smooth, that is done by scraping with a pyramidal tool called a *rimer* or *broach.*

The *pressure* required for shearing or for punching may be calculated by means of the following formula:—

$$P = f c t; \qquad \text{(1.)}$$

in which t is the thickness of the plate to be shorn or punched; c, the length of the cut; that is, the breadth of the plate, for shearing, on the circumference of the hole, for punching; so that $c\,t$ is the area of shorn surface; and f, the co-efficient of ultimate resistance to shearing; which may be estimated, for malleable iron, at

50,000 lbs. on the square inch, or
35 kilogrammes on the square millimètre.

The *work* of shearing or punching is estimated by Weisbach (*Ingenieur*, § 129) as equal to that of overcoming the resistance P through *one-sixth of the thickness of the plate*; that is to say, it is expressed by

$$\frac{P\,t}{6} = \frac{f\,c\,t^2}{6}; \qquad \text{(2.)}$$

and this is the net, or useful work. The same author estimates the counter-efficiency of shearing and punching machines at from $1\frac{1}{3}$ to $1\frac{1}{2}$; so that taking the higher of those estimates, the total work of such a machine at one stroke is

$$\frac{P\,t}{4} = \frac{f\,c\,t^2}{4}; \qquad \text{(3.)}$$

and this formula is to be used in calculating the power required to drive such machines, and the dimensions of their fly-wheels (see page 410).

480. **Paring and Scraping Tools in General.**—The general nature of the modes of action of paring and of scraping tools is illustrated by figs. 284 and 285; paring being represented by fig. 284; scraping by fig. 285. In each figure, the tool is supposed to act upon a cylindrical piece of work in a turning lathe. The arrow in each figure represents the direction of motion of the work relatively to the tool. The plane of each figure is parallel to the direction of the cutting motion, and perpendicular to the face of the work. The point A is the trace of the cutting edge of the tool. F A B is a normal to the face of the work, and is also the trace of a plane normal to the direction of the cutting motion. A C is the trace of a plane tangent to the face of the work. Had the process represented been planing instead of turning, A C would have been the trace of the face of the work itself. A D is the trace of the *face-plane* or *front-plane* of the cutting edge. The angle A C D is called by Babbage the *angle of relief.*

A E is the trace of the *upper plane* of the cutting edge: so called because of its position in the process of turning, when the plane

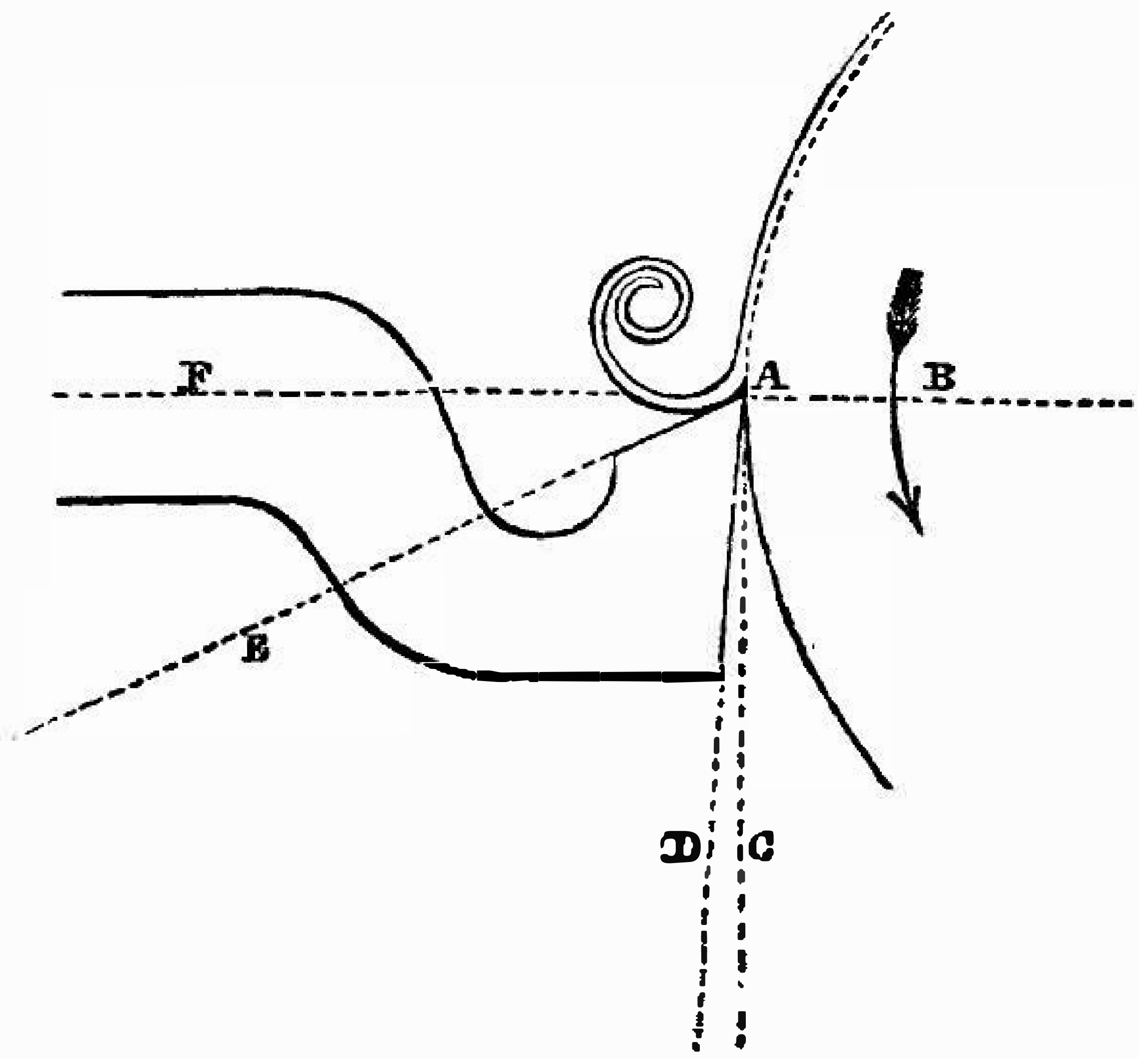

Fig. 284.

A C is vertical, and the tool cuts upwards. In other operations, such as planing and slotting, the plane A E may be turned

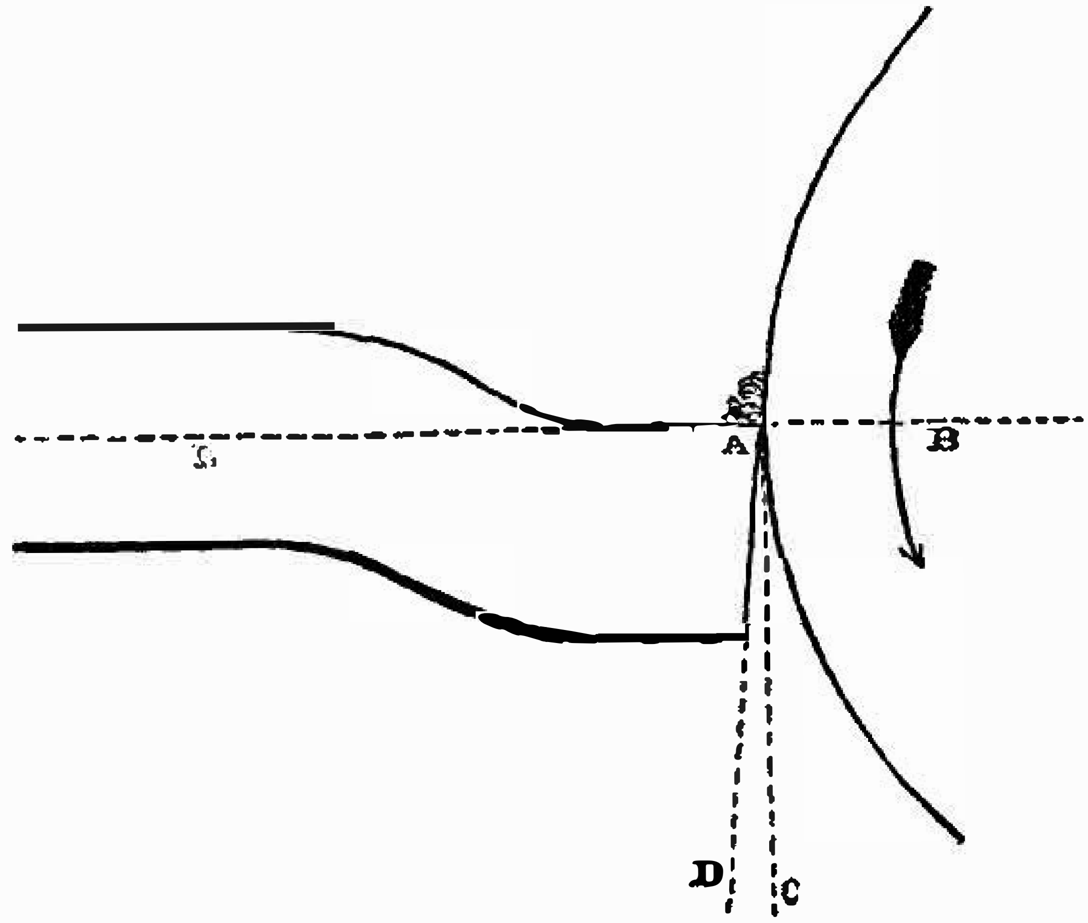

Fig. 285.

forwards or downwards; the fact being, that in every case it is the real front plane as regards the cutting motion; but the custom is to call it the upper plane.

D A E is the *angle of the tool*, or *cutting angle.* In paring tools the cutting angle is always acute, as in fig. 284; having values depending on the nature of the material to be cut, of which examples will be given further on. In scraping tools, the cutting angle may be acute, right, or obtuse; in fig. 285, it is nearly a right angle.

The angle C A E, made by the upper plane A E with the tangent plane A C, may, for the sake of convenience, be called the *working angle;* so that the *working angle is equal to the sum of the cutting angle and the angle of relief;* or in symbols, C A E = D A E + C A D.*

It is upon the working angle that the distinction between properly shaped paring and scraping tools depends. That distinction may be stated as follows:—*Every paring tool has an acute working angle; every right or obtuse working angle makes a scraping tool.*

An acute working angle, if it is too great to suit the material on which it acts, may give a scraping instead of a paring tool.

As regards the effect of the *cutting angle* upon the action of a tool, it is obvious, that as the working angle is greater than the cutting angle, an obtuse or even a right cutting angle gives a scraping tool; and that an acute cutting angle too may give a scraping tool, if the tool is held so as to make the working angle right or obtuse; but that an acute cutting angle is essential to a paring tool.

In well-made paring tools, the difference between the working angle and the cutting angle, or *angle of relief*, C A D, is not made greater than experience has proved to be necessary in order to prevent excessive friction between the face-plane of the tool and the face of the work; that is, about 3°. Any increase of that angle is to be avoided; because it tends to make the tool dig into the work, and to produce "chattering;" and because, by diminishing the cutting angle, it weakens the tool.

The position of the shaft of the tool as held by the tool-holder should in all cases be such that the back and forward motion of adjustment of the cutting edge, A, by which the depth of the cut is regulated, shall take place exactly in the plane F A B, perpendicular to the face of the work; that is to say, in the case of a turning lathe, in a plane traversing the axis of rotation.

The tools shown in the figures have the front ends of their shafts bent, *hooked*, or *cranked*, as it is termed, in such a manner as to

* Mr. Babbage calls E A F the *angle of escape;* so that the angle of escape is the complement of the working angle. In carpenters' hand-planes, the working angle is called the *pitch*.

ensure that the cutting edge, A, shall *not be in advance of the axis of the straight part of the shaft of the tool.* The object of this arrangement is, that any deflection which the tool-shaft may undergo through excessive resistance to the cut, may tend to move the cutting edge, A, away from the work, and not to make it dig into it.

In tools for rough work, and having very stiff shafts, the cranked shape is unnecessary; and then the upper side of the shaft is in the plane B A F; the proper position of the upper plane of the cutting edge being given by means of a hollow or *flute* in the upper side of the tool.

Fig. 286 represents a paring tool designed on the same principles with that shown in fig. 284, but with two cutting edges, and a three-sided pyramidal point. The upper part of the figure, marked with capital letters, is an elevation; the lower part, marked with italic letters, is a plan, or horizontal projection; and corresponding letters mark corresponding points. The cutting edges in the plan are marked *a b* and *a c*; *a b e d* and *a c f d* are the projections of the two face-planes; *a d* is the projection of the *front edge;* and *a b g h c* that of the upper plane. In the elevation are shown one of the cutting edges, A B; one of the face-planes, A B E D; and the front edge, A D. Sometimes the front edge is rounded, together with the angles *c a b* and *f d e*; thus connecting the two straight cutting edges by means of a short curved cutting edge. Sometimes the whole cutting edge is a curve; and then, instead of two face-planes, there is a cylindrical front surface.

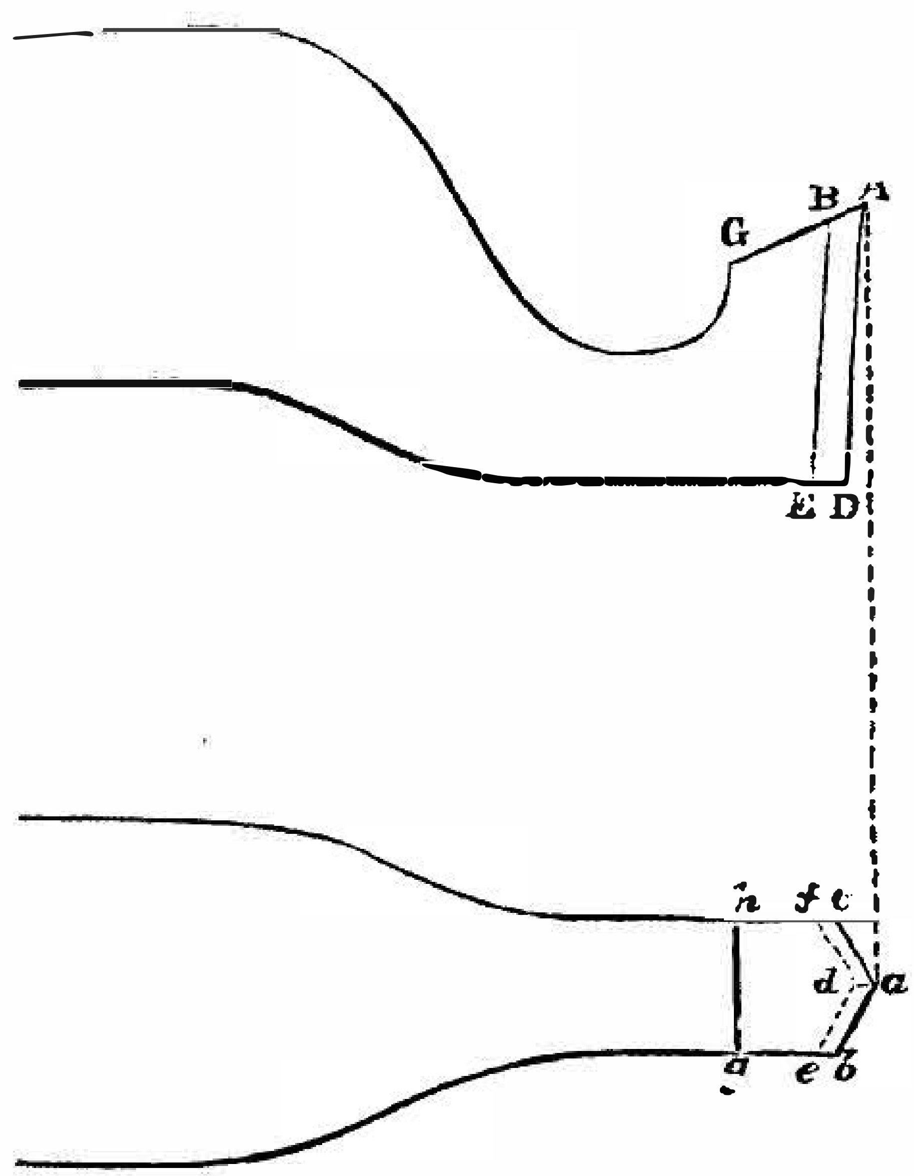

Fig. 286.

The relations amongst the angles made by the planes and edges of such a tool as that shown in fig. 286 may be determined either by spherical trigonometry, or by the rules in descriptive geometry given in this book, Articles 24 to 30, pages 9 to 12. They are treated of also in an essay by Mr. Willis, already mentioned as having been published in the appendix to the second volume of Holtzapffiel *On Mechanical Manipulation*.

A tool with one curved or two straight cutting edges may be used to cut a groove, or to pare a layer by successive shavings off the surface of a piece of work. In theelatter case the shaft of the tool is to be so formed and held, that one of the straight cutting edges (for example, *a b*), or one side of the curved edge, touches the pared face of the work, and the other (for example, *a c*) cuts into the side of the unpared part of the layer that is being removed; andeaccording as the tool is shaped and placed so as toelieetoethe right or to the left of the unpared part of the layer, it is called a *right-side* or a *left-side* tool. Thus, in a right-side tool, *a b* touches the pared face; *a c*, the side of the unpared layer; and in a left-side tool, *ac* touches the pared face, and *a b* the side of the unpared layer. A tool with onecuttingedgewhich is parallel to the face of the work, as in fig. 284, or a tool with two cutting edges, as in fig. 286, making equal angles with the face, is called a *face-tool*.

Fig. 287 shows how the principle of having a small angle of relief, with a sufficiently acute cutting angle, is applied to *drills* or *boring bits*. The figure shows a front view, lettered A, B, C, &c.; an edge view, lettered A', B', C', &c.; and an end view, lettered in italics. A A is the axis of rotation; B C, B C, the cutting edges; and the requisite acuteness is given to the cutting angle (marked D' C' E' in the edge view) by means of a *flute* or curved hollow parallel to each of the cutting edges.

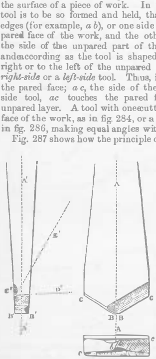

Fig.e287.

481. **Cutting Angles of Tools.**—The best cutting angles for *paring tools* suited to different materialsehave been ascertained by practical experience. The following are the principal results:—

Materials.	Cutting Angles.
Wood,	from 20° to 45°
Iron and Steel,	from 60° to 70°
(The smaller angles for the softer kinds; the greater for the harder.)	
Brass and Bronze,	80° and upwards.

In the case of scraping tools, the size of the cutting angle is a question mainly of convenience and strength; for the same tool which is a paring tool, when the working angle is only a little greater than the cutting angle, becomes a scraping tool when the working angle is sufficiently increased.

It may be considered, however, that in order to give sufficient strength to the tool, the *least* cutting angle for a scraping tool should not be less than the cutting angle of a paring tool suited to the same material.

The cutting angle of scraping tools for iron ranges from 60° to nearly 135°; the former value being met with in triangular scrapers for finishing plane surfaces; the latter, in octagonal *broaches* for enlarging and correcting conical holes.

482. **Speed of Cutting Tools.**—The speed of the cutting motion of tools is limited by the heat produced by their action: it must not be so great as to cause that heat to affect the temper of the steel. Hence it is less, the harder the material of the work. The following are examples.

Material.	Speed of Cutting Motion. Feet per Minute.
White Cast Iron, ...	about 5
Steel, and Gray Cast Iron, ...	from 10 to 20
Wrought Iron, ...	from 15 to 25
Brass and Bronze, ...	from 40 to 100
Wood, ...	from 300 to 2000

Higher speeds may be used for planing, and for ordinary turning, where the tool and the cut surface are freely exposed to the air, than for drilling and boring.

483. **Resistance and Work of Paring Tools.**—The following estimate of the resistance to the motion of a tool paring iron, and of the work done, is based on that given by Weisbach:—

Let R denote the resistance to the cutting motion of the tool; b the breadth, and t the thickness of the shaving which it pares off; so that $b\,t$ is the sectional area of the shaving; then

$$P = f\,b\,t; \quad\text{.........................(1.)}$$

in which f is a co-efficient depending on the hardness and toughness of the material. The value of f for iron is estimated by Weisbach at 50,000 lbs. on the square inch, or 35 kilogrammes on the square millimètre. For steel, it is probably from once-and-half to twice as great. Let l be a given length of shaving; then the work done in paring that length off is

$$P\,l = f\,l\,b\,t. \quad\text{.........................(2.)}$$

Let w be the heaviness of the material; then $w\,l\,b\,t$ is the weight of material pared off; and the work done in that process is evidently equal to *the work of lifting that weight to the height* $\frac{f}{w}$; whose value for iron is

15,000 feet, or
4,570 mètres.

The *counter-efficiency* of the machines in which paring tools are used may be estimated at from 1·3 to 1·5; or say, on an average, 1·4; so that the total work of a machine in paring away a given weight of iron may be estimated as being equal to that of lifting the same weight to a height of

21,000 feet, or
6,400 mètres.

The work done by cutting tools produces heat, which, unless abstracted, tends to injure the tools by raising their temperature. In order to abstract the heat and keep the temperature moderate, the point of the tool, in cutting wrought iron and steel, is moistened with a suitable liquid, such as oil, or a solution of carbonate of soda in water. Pure water should not be used, as it causes iron and steel to rust. Cast iron, brass, and bronze are cut with dry tools.

484. **Combinations of Cutting Tools.**—The boring bit, already mentioned in Article 480, page 566, is in fact a combination of two cutters or paring tools. A combination of several paring tools, working side by side, is seen in the tool sometimes called a *comb*, used in screw-cutting lathes, for cutting several turns of the thread at the same time. Cutters following each other in succession occur in taps and dies, for cutting internal and external screws by hand. A circular cutter, or *rose-cutter*, used in shaping the teeth of wheels, is itself a toothed wheel, each of its teeth being a paring tool. The teeth of a saw form a series of small paring tools or scraping tools, according to their working angles; and by the process of *setting* them—that is, bending them alternately to the right and left—they are made alternately into left-side and right-side tools, so as to cut the two sides of the saw-kerf.

485. **Motions of Machine-Tools in General.**—In most examples of machine-tools, the relative motion of the tool and the work is the resultant of threee component motions, usually at right angles to each other, or of two out of those three: the cutting motion, the traversing motion, or transverse feed motion, and the advancing feed motion; the first two taking place parallel to the face of the work, and the third in a direction normal to it.e

The *cutting motion* is the most rapid of the three, being that by which the tool acts on the face of the work, leaving a narrow strip or band from which a portion of the material has been pared or scraped away. In many instances, the cutting motion is effected by a motion of the work, the tool remaining fixed, and such is the case especially in turning and screw-cutting lathes, and in almost all planing machines. There are other operations in which the cut is made by a motion of the tool; such as drilling, boring, slotting, and shaping. The speed of the cutting motion has been already mentioned in Article 482, page 567.

The *transverse feed motion* takes place parallel to the face of the work, and at right angles to the cutting motion: it is that motion by which the tool is made to shift its position relatively to the work, so as to make a series of parallel cuts side by side, leaving a series of strips or bands which compose a surface of any required extent. It is sometimes continuous, and sometimes intermittent. The general nature of transverse feed motions has already been described in Article 258, page 293.

The *rate* at which the traversing motion takes place in paring a continuous surface depends on the breadth of the cut; which, in iron, ranges from 0·01 to 0·05 inch (= from 0·25 to 1·25 millimètre). In screw-cutting, the traverse at each revolution is equal to the pitch of the screw.

The *advancing feed-motion* is that by which, after a certain depth of material has been cut away from the face of the work, the tool is advanced so as to cut away an additional depth. This is very often an intermittent motion; and in turning and planing machines it is usually an adjustment, made from time to time by hand. Its extent, at each adjustment, is equal to the depth of the cut; which, in iron, ranges from the smallest appreciable quantity up to 0·75 inch (= 19 millimètres) in ordinary cases.

486. **Making Ruled Surfaces—Planing—Slotting—Shaping.**—A ruled surface is one in which every point is traversed by a straight line lying wholly in the surface. Such a straight line is called a *generating line* of the surface; and the surface may be regarded as generated by the motion of the straight line. A ruled surface may be cut to any required degree of precision, by the successive strokes of a tool, each stroke being made along a straight generating line of the surface.

The class of ruled surfaces comprehends the following different kinds, amongst others:—

I. All *straight surfaces:* that is, surfaces in which the straight generating lines are all parallel to each other. Such surfaces may be either plane or cylindrical; the term cylindrical surfaces embracing not only those whose transverse sections are circular, but those whose transverse sections are curves of any figure, such as the acting surfaces of the teeth of spur-wheels (Article 130, page 120). It has already been stated, in Article 38, page 17, that the bearing surfaces of sliding primary pieces must all be straight.

II. All *conical surfaces:* that is, surfaces in which the straight generating lines all pass through one point. The transverse sections of such a surface may be circular, as in the pitch-cone of a circular bevel wheel (Article 105, page 86); or they may be non-circular curves, as in the acting surfaces of the teeth of such a wheel (Article 144, page 143).

III. *Hyperboloidal or skew-bevel surfaces:* in which the straight generating lines, not intersecting in one point, traverse a series of similar transverse sections of the surface. Such transverse sections may be circular, as in the pitch-surface of a circular skew-bevel wheel (Article 106, page 87); or non-circular, as in the acting surfaces of skew-bevel teeth (Article 145, page 146).

The Planing Machine cuts straight surfaces of all kinds; and is used especially for the cutting of plane surfaces to a certain degree of approximation; that is to say, the *longitudinal straightness* of the surface is perfect; but the transverse straightness is approximate. In a planing machine of ordinary construction, there is a fixed horizontal *bed*, very strongly and stiffly supported: its essential parts being a pair of most accurately made straight, parallel, horizontal guides, of a V-shape in cross-section. In those guides there slides a pair of straight, parallel, horizontal, triangular bars, forming the supports of a stiff and strong horizontal *table*, having in it several *slots* or oblong openings, for the purpose of enabling the *work* to be secured to it. From the two sides of the bed rise a pair of standards, carrying a straight horizontal saddle that bridges across the table. The saddle, by means of straight horizontal guides, supports the tool-holder, which has a transverse traversing motion. The sliding surfaces of the saddle and tool-holder are usually of a dove-tail shape in cross-section.

The cutting action is effected by a longitudinal motion of the table carrying the work: the gearing which communicates that motion ought to be extremely smooth and accurate in its action; such as the rack and helical pinion described at page 289; and the pitch-point of the rack and pinion ought to be as directly as possible below the cutting tool. As to the speed, see Article 482, page 567.

During the return stroke, the tool is lifted clear of the work, and the motion of the rack and pinion is reversed by means of self-acting reversing gear; such, for example, as that mentioned in Article 264, page 299; and the train of wheelwork which produces the return stroke is so proportioned as to give an increased speed of motion to the table, usually about double that of the cutting stroke.

The transverse traversing motion of the tool-holder is intermittent, being made during the return stroke of the table. The combination which directly produces it is usually a transverse horizontal screw driving a nut that is fixed to the tool-holder.

The screw is driven by a suitable train of wheelwork, the first wheel of which is driven by a click, usually of the reversible kind (Article 194, page 207). The extent of traverse after each cutting stroke can be regulated by the help of adjustments of length of stroke (Article 273, page 312), or of change-wheels (Article 271, page 311).

In some large planing machines for very heavy work, the cutting stroke is effected by a longitudinal motion of a strong frame carrying the saddle and the tool-holder; the table with the work being at rest.

For cutting straight surfaces of more or less complex cross-section, and especially for cutting straight grooves and straight rectangular holes, such as key-ways and slots, the SLOTTING-MACHINE is used. In this machine the tool-holder or cutter-bar usually slides vertically in a guiding groove in the *slide-head*, which is carried by a strong overhanging frame. Below the slide-head is a table to which the work is secured, capable of being turned about a vertical axis, and traversed horizontally in two rectangular directions, so as to bring the work into any required position relatively to the cutting-tool.

A SHAPING MACHINE differs from a slotting machine mainly in having a slide-head that is capable of being turned into different positions, so as to cause the tool to make strokes in different directions when required. It is used for cutting ruled surfaces of various kinds. Circular cutters (page 568), driven by suitable shifting trains (Article 228, page 235), are sometimes used in shaping machines.

487. **Scraping Plane Surfaces.**—When the highest practicable degree of accuracy is required in a plane surface, its form may in the first place be given approximately by the planing machine, but it must be finished by the hand-scraper. Scrapers for iron are usually made of very hard steel, with edges of 60°.

When an existing standard plane surface (or *planometer*, as it is sometimes called) is available, it is smeared with a very thin coating of a mixture of red chalk and oil. The new plane, in its approximate condition, is laid face to face on the standard plane, and gently rubbed on it. The prominent places on the new plane pick up the colouring matter, and are marked by it; and thus the workman is guided to the parts that require scraping down. The process is repeated again and again until the new plane fits the standard plane with the required degree of precision.

In the absence of a standard plane, three approximately plane cast-iron plates are made, stiffened at the back by ribs. One pair of those are taken in the first place; and one of them being smeared with a suitable mixture, they are repeatedly rubbed together, so as to mark the prominent places, and *both* are scraped, until they fit each other with a certain degree of accuracy. At this stage of the process, they may be both plane; or both spherical, and of the same radius, one being convex and the other concave. Then the two plates first taken are compared in succession with the third plate, and the operations of rubbing and scraping repeated, with the plates combined by pairs in every possible way, until all three plates accurately fit each other in every combination and position; when they must necessarily be truly plane. This is the process by which standard planes are made; and when a set of three have been made, it is usual to reserve one of them very carefully for testing from time to time the accuracy of the other two, which are employed as standards of planeness and straightness for ordinary use.

488. **Making Surfaces of Revolution — Turning, Drilling, and Boring.**—A turning-lathe usually contains the following principal parts. The *bed*, truly plane and horizontal. The *head-stocks*, or supports for the axis of rotation of the work; one fixed, and the other capable of being shifted longitudinally on the bed to a greater or less distance from the fixed headstock, so as to suit the size of the work. The *saddle*, which slides longitudinally on the bed, carrying the *rest*, which carries the tool-holder. The rest has longitudinal and transverse traversing motions, usually produced by means of screws and nuts, acting on slides with dove-tail-shaped straight bearing surfaces; the position of the tool-holder is adjustable vertically and horizontally.

The longitudinal traversing motion of the saddle is sometimes produced by a pinion driving a rack, like the motion of the table in a planing machine, and sometimes by a strong and very accurately made screw, extending the whole length of the bed; the latter method is used in screw-cutting lathes. Many lathes are provided both with a guide-screw and with a rack-and-pinion motion for traversing, either of which can be used at pleasure. The guide-screw is commonly reserved for screw-cutting, and the rack and pinion used for ordinary purposes.

The moveable headstock carries the *screw-spindle*, which does not rotate, but can be slid back and forward by means of a screw, in order to adjust the position of its point, which forms one of the supports of the work. The fixed or fast headstock carries the *lathe-spindle*, which is a rotating horizontal shaft, driven at a proper speed by means of a suitable belt and pulleys; the speed is capable of adjustment by means of speed-cones, usually of the stepped kind described in Article 171, page 185.

The journals of the lathe-spindle are in most cases made slightly conical, and are tightened in their bearings, when required, by means of screws acting endwise.

The ends of both spindles project inwards from the headstocks: they are capable of being fitted with various contrivances for supporting and holding the work. The screw-spindle usually, and the lathe-spindle sometimes, is fitted with a conical point of steel called a *centre*, the angle at the point ranging from 60° for wood, to 80° or 90° for metal; such points support the work and keep it truly centred on the axis of rotation. The lathe-spindle can also be fitted with *chucks* of different sorts; being discs provided with holes, pins, and other means of holding the work, and causing it to rotate along with the lathe-spindle; or with a *mandril* or cylindrical continuation of the spindle, on which wheels and pulleys, and other pieces of work having eyes in their centres, can be keyed for the purpose of being turned.

A chuck in the form of a large circular disc is called a *face-plate*. Some lathes have face-plates on both spindles; and then the two spindles are driven at the same speed, by means of two pinions on one shaft, gearing with teeth on the rims of the face-plates.

The greatest radius of the work which can be turned in a given lathe is limited by the height of the axis of rotation above the bed; and the lathe is described as a "twelve-inch lathe," a "twenty-four-inch lathe," &c., according to that height.

The tool-holder is adjusted so that the point or cutting part of the tool is exactly in a horizontal plane traversing the axis of rotation. The direction of rotation is such that the surface of the work moves *downwards* at the point of the tool, which accordingly cuts upwards.

The screws and nuts, or the pinions and racks, by which the traversing motions of the tool-holder are produced, are driven from the lathe-spindle through trains containing *change-wheels* (Article 271, page 311); and by means of these the velocity-ratio and directional-relation of the cutting motion and of the traversing motion can be adjusted so as to produce the required resultant or aggregate relative motion. As to the rate of traverse per revolution, see Article 485, page 569.

When the word *traversing* is used without qualification, it generally means that the tool traverses in a direction parallel to the axis of the lathe, so as to turn a cylindrical surface. When the tool is made to move in the direction of a radius perpendicular to the axis, it turns a plane surface; and the process is called *surfacing*. This is very often the means used of making a plane approximately, previous to correcting it by scraping. By combining those two motions, so as to make the tool traverse in a straight line cutting the axis obliquely, a conical surface is turned. When the point of the tool is made to traverse in a circle, one diameter of which coincides with the axis, a spherical surface is turned. A hyperboloidal surface might be turned by making the point of the tool traverse along one of its straight generating lines (see Article 84, page 70; Article 106, page 87).

All the preceding operations are examples of *circular turning*, in which the point of the tool describes, relatively to the work, a circle about the axis, if the traversing motion be neglected, or a helix or spiral of a pitch equal to the traverse per revolution, if this component of the motion be taken into account. In *eccentric turning*, the point is made to describe, relatively to the work, paths of various other kinds, such as eccentric circles, ellipses, epicycloids, and arbitrary curves of various sorts. Such *aggregate paths* are produced, sometimes by epicyclic trains carried by the chuck which holds the work, as in the *eccentric chuck*, *elliptic chuck*, and *geometric chuck;* sometimes by the action of cams or shaper-plates on the tool-holder. The actions of such combinations have been treated of in Part I., Chapter V., Section IV., pages 261 to 267; and in the Addenda, pages 290, 291.

Drilling and *Boring* may be looked upon as modifications of turning, applied to the making of concave surfaces of revolution, and especially of hollow cylinders. The word boring is often applied to both processes; but when drilling and boring are distinguished from each other, *drilling* means the making of a cylindrical hole by a tool which advances endways, cutting shavings from the flat or conical bottom of the hole (see fig. 287); and *boring*, the enlarging and correcting of a hollow cylindrical surface already made; such as that of a cast-iron steam-engine cylinder.

In *drilling*, the tool or drill usually rotates about a vertical axis; and it is very often driven by a shifting train, carried by a *jib* or train-arm. (As to shifting trains, see Article 228, pages 235 to 238.) This is in order that the position of the drill may be shifted to various parts of the work. The train-arm or jib projects horizontally from a strong hollow standard, containing the vertical shaft that drives the shifting train. The work is supported by a table, which is often made so as to be capable of being turned about a vertical axis, and shifted horizontally on slides in two rectangular directions, in order to bring different points in the work below the drill.

The *feed-motion* is given sometimes by gradually lowering the drill, sometimes by gradually raising the table.

In a *multiple drilling machine* (used for making rows of holes in iron plates) a set of drills are driven from one shaft by means of skew-bevel pinions or other suitable mechanism. The feed motion is given by raising the table. The forms of drilling tools are very various.

In a *boring machine*, the inner surface of a hollow cylinder is pared by means of one or more tools carried by a *cutter-bar* or *cutter-head;* being a cylinder a little smaller than the hollow cylinder to be bored. When the work is a very large cylinder, it is usually fixed; and the rotation and traversing motion are both given to the cutter head.

489. **Screw-Cutting.**—The operation of cutting screws is per-

formed in a lathe; the work rotates, and the tool-holder is made to traverse longitudinally by means of the *guide-screw*, already mentioned at page 572. The nut by means of which the guide-screw drives the saddle is a *clasp-nut* (see Addenda, page 576): which can be thrown into or out of gear with the guide-screw when required. The guide-screw is made with great care and precision. An ordinary value of its pitch is half an inch. The velocity-ratio and directional-relation of the motions of the guide-screw and of the lathe-spindle are adjusted by means of change-wheels to the pitch and direction of the screw to be cut, according to the following principles.

I. $$\frac{\text{Speed of Rotation of Guide-Screw}}{\text{Speed of Rotation of Lathe-Spindle}} = \frac{\text{Pitch of New Screw}}{\text{Pitch of Guide-Screw}}.$$

II. The direction, right or left-handed, of the new screw, is similar or contrary to that of the guide-screw, according as the directions of rotation of the guide-screw and of the lathe-spindle are similar or contrary.

490. **Wheel-Cutting.**—A wheel-cutting machine, for shaping the teeth of wheels, may be regarded as a special form of the shaping machine, in some cases combined with the turning lathe. The wheel to be cut is fixed on mandrils carried at the end of a rotating spindle, mounted on a head-stock. Sometimes that spindle acts as a lathe-spindle, while the wheel is being turned. When the pitching and tooth-cutting are to be begun, a large worm-wheel, permanently fixed on the spindle, is made to gear with a tangent screw, by means of which it is successively turned through a series of angles, each equal to the pitch-angle; first, for the purpose of pitching the wheel, or marking the pitch-points of the teeth on the pitch-circle, and then for the purpose of changing the position of the wheel after each tooth has been cut, preparatory to cutting the next tooth. The figures of the teeth are given approximately by casting, and finished by cutting.

Each stroke of the cutter is guided so as to take place along a straight line. In spur-wheels that straight line is parallel to the axis; in bevel wheels, it traverses the apex of the pitch-cone; in skew-bevel wheels, it is a generating line of the hyperboloidal surfaces of the teeth. When a single cutter is used, the slide in which it works is guided into the proper positions for the successive strokes by a templet shaped like a tooth or like the space between two teeth. In cutting the teeth of spur-wheels, a rotating circular cutter is used; and the form of the cutting edges of its teeth is the counterpart of that of the space between two teeth.

The cutting of worm-wheels by means of a rotating cutter which is a copy of the screw that is to gear with the wheel, has already been mentioned in Article 157, page 166.

Addendum to Article 263, Page 298.

Clasp-Nut.—In certain machine-tools, the traversing motion of the tool-holder is produced by a screw which rotates about a fixed axis, and drives longitudinally (as described in Article 152, page 157) a nut that fits it truly, without pinching it. That nut is made in two halves, capable of being clasped round the screw or unclasped, according as the combination is to be thrown into or out of gear. When the combination is about to be thrown into gear, either the nut or the screw must, if required, be shifted longitudinally, so as to bring the threads of the one opposite to the grooves of the other.

Addendum to Table V., Page 482.

Strength and Elasticity of Silk and Flax.—

	Silken Thread.	Flaxen Thread.	Flaxen Yarn in Canvas.
Ultimate tenacity—			
In lineal feet of material,	120,000	95,000	from 52,000 to 59,000
In mètres, ...	36,600	29,000	from 15,900 to 18,000
Modulus of elasticity—			
In lineal feet of material,	3,000,000		
In mètres, ...	914,400		

Addendum to Article 465, Page 547; and Article 466, Page 549.

Braced Shaft.—The description given in Article 459, page 539, of a braced connecting-rod, applies also to the general construction of a braced shaft. The object of that construction is to diminish the deflection and the bending stress of a shaft of long span, through the support given to the shaft at the middle of the span by the bracing. The following is the easiest way of computing the dimensions:—The diameter of the shaft, h, is to be calculated so as to bear safely the twisting moment, combined with a bending moment due to half the actual span. Let c be that half-span; and y the length of one of the arms of the bracing cross, which is to be fixed according to convenience. Let $\frac{f}{w}$ be the safe working tension of the bracing rods, in length of themselves; say, 3,000 feet, or 900 mètres. Let d be the proper diameter for a tension-rod. Then the proper ratio for the diameter of each of the four tension-rods to the diameter of the shaft is given by the following formula:—

$$\frac{d}{h} = \sqrt{\left\{\frac{\frac{2wc^2}{fy}}{1 - \frac{2wc^2}{fy}}\right\}}.$$

The tension-rods should be tightened by means of screws just sufficiently to prevent any perceptible slackness of the rods which successively come uppermost as the shaft rotates.

Additional Authorities.

Dynamics of Machines:—Moseley's *Mechanics of Engineering.*

Construction of Machines:—D. K. Clark *On the Exhibited Machinery of* 1862 (especially Part III., pages 128 to 210).

Comparative Table of French and British Measures.

	No.	Log.	Log.	No.	
Grains in a gramme, ...	15.43235	1.188432	$\bar{2}$.811568	0.064799	Gramme in a grain.
Pounds avoird. in a kilogramme,	2.20462	0.343334	$\bar{1}$.656666	0.453593	Kilog. in a lb. avoirdupois.
Ton in a tonne, ...	0.984206	$\bar{1}$.993086	0.006914	1.01605	Tonnes in a ton.
Feet in a mètre, ...	3.2808693	0.515989	$\bar{1}$.484011	0.30479721	Mètres in a foot.
Inch in a millimètre, ...	0.03937043	$\bar{2}$.595170	1.404830	25.39977	Millimètres in an inch.
Mile in a kilomètre, ...	0.621377	$\bar{1}$.793355	0.206645	1.60933	Kilomètre in a mile.
Square feet in a square mètre, ..	10.7641	1.031978	$\bar{2}$.968022	0.0929013	Square mètre in a square foot.
Square inch in a square millimètre, ...	0.00155003	$\bar{3}$.190340	2.809660	645.148	Square millim. in a square inch.
Cubic feet in a cubic mètre, ...	35.3156	1.547967	$\bar{2}$.452033	0.0283161	Cubic mètre in a cubic foot.
Foot-pounds in a kilogrammètre,	7.23308	0.859323	$\bar{1}$.140677	0.138254	Kilogrammètre in a foot-pound.
Pounds-to-the-foot in a kilogramme-to-the-mètre, ...	0.671963	$\bar{1}$.827345	0.172655	1.48818	Kilogrammes-to-the-mètre in a pound-to-the-foot.
Pounds-to-the-square-foot in a kilogramme-to-the-square-mètre, ...	0.204813	$\bar{1}$.311356	0.688644	4.88252	Kilogrammes-to-the-square mètre in a pound-to-the-square-foot.
Pounds-to-the-square-inch in a kilog.-to-the-square-millimètre, ...	1422.31	3.152994	$\bar{4}$.847006	0.000703083	Kilog.-to-the-square-millimètre in a pound-to-the square-inch.
Pounds-to-the-cubic-foot in a kilogramme-to-the-cubic-mètre, ...	0.062426	$\bar{2}$.795367	1.204633	16.019	Kilogrammes-to-the-cubic mètre in a pound-to-the-cubic-foot.
Fahrenheit-degrees in a centigrade-degree, ...	1.8	0.255273	$\bar{1}$.744727	0.5555	Centigrade-degree in a Fahrenheit degree.
British units of heat in a French unit, ...	3.96832	0.598607	$\bar{1}$.401393	0.251996	French units of heat in a British unit.

	No.	Log.	Log.	No.	
Cubic inch in a cubic millimetre,	0·000061025	$\bar{5}$·785511	4·214489	16,387	Cubic millimetres in a cubic inch.
Yards in a metre,	1·0936231	0·038868	$\bar{1}$·961132	0·91439180	Metre in a yard.
Square yards in a sq. metre,	1·19601	0·077735	$\bar{1}$·922265	0·836112	Square metre in a square yard.
Cubic yards in a cubic metre,	1·30799	0·116603	$\bar{1}$·883397	0·764534	Cubic metre in a cubic yard.
Sq. miles in a sq. kilometre,	0·386109	$\bar{1}$·586710	0·413290	2·589941	Square kilometre in a sq. mile.
Acres in a hectare,	2·4711	0·392889	$\bar{1}$·607111	0·4046782	Hectare in an acre.
Mean geographical mile in a kilometre, nearly,	0·54	$\bar{1}$·73236	0·26764	1·852	Kilometres in a mean geographical mile, nearly.
Gallon in a litre,	0·220215	$\bar{1}$·342847	0·657153	4·54102	Litres in a gallon.
£ sterling in a franc,	0·039651	$\bar{2}$·598255	1·401745	25·22	Francs in a £ sterling.
Shilling in a franc,	0·79302	$\bar{1}$·899285	0·100715	1·261	Franc in a shilling.
Penny in a centime,	0·09516	$\bar{2}$·978466	1·021534	10·508	Centimes in a penny.
Horse-power in a force de cheval,	0·98633	$\bar{1}$·99402	0·00598	1·01386	Force de cheval in a horse-power.
£ per foot in a franc per metre,	0·012086	$\bar{2}$·082266	1·917734	82·74	Francs per metre in a £ per foot.
£ per square foot in a franc per square metre,	0·0036836	$\bar{3}$·566277	2·433723	271·48	Francs per square metre in a £ per square foot.
£ per cubic foot in a franc per cubic metre,	0·00112276	$\bar{3}$·050288	2·949712	890·66	Francs per cubic metre in a £ per cubic foot.
£ per lb. avoirdupois in a franc per kilogramme,	0·017986	$\bar{2}$·254921	1·745079	55·61	Francs per kilogramme in a £ per lb. avoirdupois.
£ per acre in a franc per hectare,	0·016046	$\bar{2}$·205365	1·794635	62·321	Francs per hectare in a £ per acre.
£ per gallon in a franc per litre,	0·18006	$\bar{1}$·255408	0·744592	5·5538	Francs per litre in a £ per gallon.