rotates a less number of times per minute than S_2. By increasing the number of speeds a greater amount of variation can be obtained; however, it is not usual to employ more than six speeds.

63. The common quantity a is termed the *fall* or *step*; if the diameter of the smallest pulley $= b$, then the diameter of $c = b + 2a$, and the diameter of $d = c + 2a$; thus, let the diameter of $b = 12''$, and $a = 1\frac{1}{2}''$, then the diameter of $c = 12'' + 3'' = 15''$, and of $d = 15'' + 3'' = 18''$.

The *sums* of the diameters of the two connected pulleys are constant, thus $b + d = 12'' + 18'' = 30''$, $c + c = 15'' + 15'' = 30''$, and $d + b = 18'' + 12'' = 30''$. The arrangement is independent of the distance between the axes e. Speed pulleys are employed in a variety of machines, of which perhaps the most common is the lathe.

64. Figs. 117-119, Plate XII., are elevations of a speed pulley; the fall is $1\frac{1}{4}''$, and the diameters of the speeds are $1'..5''$, $1'..2\frac{1}{2}''$, and $1'..0''$. In this example the pulley is fixed on the end of a shaft a, one of the bearings of which is marked e, fig. 119. Fig. 117 is an end-elevation of fig. 119 projected in the direction D. Fig. 118 is an end-elevation of fig. 119 projected in the direction E; the top half of this figure shows the inside of the pulley, the plate f having been removed; the bottom half shows the plate in position. The greater portion of fig. 119 is in section, portion of the shaft is also in section showing the mode of connection between the pulley and shaft. The plate f is connected to the pulley by means of three screws g, one of which is shown in figs. 118, 119; in the top half of fig. 118 are shown the two holes g_1, to receive the screws g: this plate is provided with a boss h, which is *bored out* to the same diameter as the shaft upon which it runs loose. k is the boss of the pulley; the connection between the shaft and pulley is made by means of a key let into this boss and the shaft; l is a washer fixed to the shaft by means of a set-screw o, its use is to prevent the pulley from working loose on the shaft. The following are the remaining dimensions:—Width of each speed $3''$; boss k $4\frac{5}{8}''$ diameter $\times$ $3\frac{1}{2}''$ through; boss h $4''$ diameter $\times$ $3''$ through; diameter of the shaft a $2\frac{1}{2}''$; thickness of metal at f $\frac{7}{16}''$, at m $\frac{5}{16}''$, and at n $\frac{7}{16}''$; diameter of set-screw o $\frac{3}{4}''$; diameter of set-screws g $\frac{1}{2}''$; washer l $3\frac{1}{2}''$ diameter $\times$ $\frac{3}{8}''$ thick; key $\frac{1}{2}''$ square and $3\frac{1}{2}''$ long. The whole is of cast-iron except the shaft a, the screws g and o, and the washer l, which are of wrought-iron, and the key, which is of steel. The outer surface of the speeds is curved as shown at pq, the amount of convexity is that stated in Art. 59, page 48.

The drawing of these figures should present no difficulty to the student, as there are no lines to be drawn other than straight ones, circles, and arcs of circles; and they should be drawn to a scale of not less than $\frac{1}{4}$. *In all cases the student should work from the written dimensions when given, rather than apply a scale to the figures, or copy off the dimensions by means of instruments.* This remark applies to all the figures in this book, and generally in all cases.

65. On the Teeth of Wheels.—In chapter VII. we considered spur and bevel wheels, without respect to the form of the teeth; we shall now proceed to state the proportions of the teeth of such wheels, and certain practical methods of drawing them, leaving the consideration of the various curves used in their construction for our Advanced Work. In Art. 47, page 41, it is stated why teeth are necessary for wheels, and in Arts. 48 and 49, page 42, we worked out an example of a pair of spur wheels in outline; we will now complete the example for the wheel A showing the teeth.

66. Before working out this example, we will give the proportions of the several parts of the teeth. It is usual

Another set of proportions is obtained by dividing the pitch into 15 equal parts, as shown in fig. 122, and making $T = \frac{5\frac{1}{2}}{15}$, $B = \frac{6\frac{1}{2}}{15}$, $W = \frac{7}{15}$, and $S = \frac{8}{15}$. There are other proportions used by different makers, which come very near to one or other of the above sets. The *form* of the tooth (efg, fig. 120) is of considerable importance; there are three chief forms in use; in the examples in this book we shall use the *cycloidal* form of tooth.

67. In figs. 123, 124, Plate XIII., is shown in elevation and plan the spur wheel of 24 teeth and $\frac{3}{4}''$ pitch, whose dimensions are given in Art. 49, page 42. We have substituted arcs of circles for the *epicycloids* and *hypocycloids* which form the curved surfaces of the teeth, as is usual in scale drawings; however, in making the wheels, the form of the teeth should be obtained correctly, and then approximations may be used for drawing purposes. The approximations employed in this example are very near the true form.

Having drawn the centre lines ex, fy, the pitch circle SP, and the circles for the top and the bottom of the teeth, divide the pitch circle into 24 equal parts; take one of the pitch points, as a, and mark on each side of it a distance $ab = \frac{1}{2}$ W; from d as a centre with a radius db (= the pitch + $\frac{1}{2}$ W) describe the top of the tooth bb; and from c as a centre with a radius cb (= the pitch − $\frac{1}{2}$ W) describe the bottom of the tooth bb' (the points d and c are the centres of the teeth on each side of a). Then bbb' is one side of a tooth; by repeating the operation its other side can be drawn, and in like manner the remaining teeth of the wheel. The student will find it better first to draw all the tops and then the bottoms of the teeth, so that only one alteration of his drawing instrument will be necessary. Fig. 123 is an elevation, and fig. 124 is a plan, of the wheel; the right-hand half of the plan is in section, as made by a plane S_1P_1, fig. 123, showing the key in position; the other half of the plan is an ordinary projection showing the teeth; the construction lines indicate how each is obtained. The top of the tooth is sometimes termed the *face*, and sometimes the *addendum*, while the bottom of the tooth is called the *flank*.

68. To facilitate the drawing of the teeth of wheels formed by cycloidal curves, an instrument has been designed by Professor Willis, by which arcs of circles are substituted for the curves; the result gives a very near approximation to the true form. The instrument is called by its inventor the *Odontograph*; fig. 125, Plate XIV., is a drawing of it to a scale of $\frac{1}{2}$. For practical use it may be cut out in card-board or sheet metal; the student will be able to construct the instrument from the figure and the following description:—Having provided a rectangular piece of card-board, $13'' \times 7\frac{1}{2}''$, upon one of its edges, as AB, take a point T about $2\frac{1}{2}''$ from B; on each side of T set off distances of $\frac{1}{2}''$; divide each of these into 10 equal parts, and number them as shown; from T draw TC so that the angle BTC contains 75°. The tables are to be copied from the figure; the top one contains the centres for the flanks, and the bottom one those for the faces of the teeth; the first column in each table contains a list of certain wheels of from 13 to 150 teeth; the whole of the wheels are not given, because the error in taking

(*To be continued.*)