the crank, and hence to find the displacement of the valve at any position of the crank we have only to draw CQ in fig. 26 parallel to the crank, when CQ represents the displacement of the valve to the scale on which the diameter of each valve circle represents the half-travel of the valve. CQ0 is the valve displacement at the beginning of the stroke shown by the arrow. Draw circular arcs *ab* and *cd* with C as centre and with radii equal to the outside lap *o* and the inside lap *i* respectively. C*a* is the position of the crank at which pre­admission occurs. The lead is *a0*Q0. The greatest steam opening is *a1*B. The cut-off occurs when the crank has the direction *Cb. Cc* is the position of the crank at release, and *Cd* marks the end of the exhaust.

63. In this diagram radii drawn from C mark the angular positions of the crank, and their intercepts by the valve circles determine the corresponding displacement of the valve. It remains to find the corresponding displacement of the piston. For this Zeuner employs a supplementary graphic construction, shown in fig. 27. Here *ab* or *a'b'* represents the connecting rod, and *bc* or *b'c* the crank. With centre *c* and radius *ac* a circle *ap* is drawn, and with centre *b* and radius *ab* another circle *aq.* Then for any position of the crank, as *cb',* the intercept *pq* between the circles is easily seen to be equal to *aa',* and is therefore the distance by which the piston has moved from its extreme position at the beginning of the stroke. In practice this diagram is combined with that of fig. 26, by drawing both about the same centre and using different scales for valve and piston travel. A radius vector drawn from the centre parallel to the crank in any position then shows the valve’s displacement from the valve’s middle position by the intercept CQ of fig. 26, and the piston’s displacement from the beginning of the piston’s motion by the intercept *pq* of fig. 27.

64. In the figures which have been sketched the events refer to the front end of the cylinder, that is, the end nearest to the crank (see fig. 23). To determine the events of steam distribution at the back end, the lap circles shown by dotted lines in fig. 26 must also be drawn, *Ca'* being the outside lap for the back end, and *Cc'* the inside lap. These laps are not necessarily equal to those at the other end of the valve. From the diagrams it will be seen that, especially with a short connecting-rod, the cut-off and release occur earlier and the compression later at the front than at the back end if the laps are equal, and a more symmetrical steam distribution can be produced by making the inside lap greater and the outside lap less on the side which leads to the front end of the cylinder. On the other hand, an unsymmetrical distribution may be desirable, as in a vertical engine, where the weight of the piston assists the steam during the down-stroke and resists it during the up-stroke, and this may be secured by a suitable inequality in the laps.

65. By varying the ratio of the laps *o* and *i* to the travel of the valve, we produce effects on the steam distribution which are readily traced by means of the diagram. Reduction of travel (which is equivalent to increase of both *0* and *i)* gives later pre­admission, earlier cut-off, later release and earlier compression; the ratios of expansion and of compression are both increased. Increase of angular advance accelerates all the events and causes a slight increase in the ratio of expansion.

66. In designing a slide-valve the breadth of the steam ports in the direction of the valve’s motion is determined with reference to the volume of the exhaust steam to be discharged in a given time, the area of the ports being generally such that the mean velocity of the steam during discharge is less than 100 ft. per second. the travel is made great enough to keep the cylinder port fully open during the greater part of the exhaust; for this purpose it is 21/2 or 3 times the breadth of the steam port. To facilitate the exit of steam the inside lap is always small, and is often wanting or even *negative.* During admission the steam port is rarely quite un­covered, especially if the outside lap is large and the travel moderate. Large travel has the advantage of giving freer ingress and egress of steam, with more sharply-defined cut-off, compression and release, but this advantage is secured at the cost of more work spent in moving the valve and more wear of the faces. To lessen the neces­sary travel without reducing the area of steam ports, double-ported valves are often used. An example is shown below in fig. 39.

67. *Reversal of Motion with Slide-Valve.—*The eccentric must stand in advance of the crank by the angle 90°+*θ*, as in fig. 28,

where CK is the crank, and CE the corresponding position of the eccentric when the engine is running in the direction of the arrow *a.* To set the engine in gear to run in the opposite direction (*b*) it is only necessary to shift the eccentric into the position CE', when it will still be 90°+*θ* in advance of the crank. In the older engines this reversal was effected by temporarily disengaging the eccentric-rod from the valve-rod, working the valve by hand until the crank turned back through an angle equal to ECE', the eccentric meanwhile remaining at rest, and then re-engaging the gear. The eccentric sheave, instead of being keyed to the shaft, was driven by a stop fixed to the shaft, which abutted on one or other of two shoulders projecting from the sheave. In some modern forms of reversing gear means are provided for turning the eccentric round on the shaft, but the arrangement known as the link-motion is now the most usual gear in locomotive, marine, winding and other engines which require to be often and easily reversed.

68. *Link-Motion.—*In the link-motion two eccentrics are used, and the ends of their rods are connected by a link. In Stephenson’s link-motion—the earliest and still the most usual form—the link is a slotted bar or pair of bars curved to the same radius as the eccentric rods (fig. 29), and capable of being shifted up or down by a suspension rod. The valve-rod ends in a block which slides within the link, and when the link is placed so that this block is nearly in line with the forward eccentric rod (R. fig. 29) the valve moves in nearly the same way as if it were driven directly by a single eccentric. This is the position of “ full forward gear.” In "full backward gear,” on the other hand, the link is pulled up until the block is in nearly a line with the backward eccentric rod R'. The link-motion thus gives a ready means of reversing the engine—but it does more than this. By setting the link in an intermediate position the valve receives a motion nearly the same as that which would be given by an eccentric of shorter radius and of greater angular advance, and the effect is to give a distribution of steam in which the cut-off is earlier than in full gear, and the expansion and compression are greater. In mid gear the steam distribution is such that scarcely any work is done in the cylinder. The movement of the link is effected by a hand-lever, or by a screw, or (in large engines) by an auxiliary steam engine. A usual arrangement of hand-lever, sketched in fig. 29, has given rise to the phrase “ notching up,” to describe the setting of the link to give a greater degree of expan­sion.

In Gooch’s link-motion (fig. 30) the link is not moved up in shifting from forward to backward gear, but a radius rod between the valve-rod and the link (which is curved to suit this radius rod) is raised or lowered—a plan which has the advantage that the lead is the same in all gears. In Allan’s motion (fig. 31) the change of gear is effected partly by shifting the link and partly by shifting a radius rod, and the link is straight.

69. *Graphic Solution of Link-Motion.*—The movement of a valve driven by a link-motion may be very fully and exactly analysed by drawing with the aid of a template the positions of the centre line of the link corresponding to a number of successive positions of the crank. Thus, in fig. 32, two circular arcs passing through *e* and *e'* are drawn with E and E' as centres and the eccentric rods are radii. These are loci of two known points of the link, and a third locus is the circle *a* in which the point of suspension must lie. By placing on the paper a template of the link, with these three points marked