circumference of the revolving wheel, and all the revolving blades are consequently in action at once. The steam streams from end to end through an annular space between a revolving drum and the casing which surrounds it. Parallel rings of fixed guide blades project inwards from the casing at suitable distances, and between these are rings of moving blades which project out­wards from the drum and revolve with it. At each step in the expansion the steam streams through a ring of fixed guide blades, and the streams so formed impinge on the next ring of moving blades, and so on. The construction, which is of great simpli­city, will be described later; it lends itself well to the generation of power on a large scale, especially in cases where a fairly high speed of rotation is wanted. The more powerful the turbine the less important do various inevitable sources of loss become; and hence, though the small turbines which were first built were less economical than reciprocating engines, the advantage is the other way where large powers are concerned.

25. Parsons introduced his compound steam turbine in 1884. For some years it was made in small sizes only, and the steam was discharged to the atmosphere without condensation. So long, however, as this was done the steam turbine was sacrificing one of its most important advantages, namely, its exceptional capacity for utilizing the energy of low-pressure steam down to the lowest vacuum obtainable in a condenser. In 1891 it was first fitted with a condenser, and it then began to he used in electric supply stations. Its efficiency at that date was found, in tests made by the present writer, to be com­parable with that of good reciprocating compound engines, but the figures then obtained were much improved on later in turbines of larger size and modified design. The first applica­tion to marine propulsion was in the “ Turbinia,” in 1897. The success of this little experimental vessel of 100 tons, which with its horse-power of 2100 made a record in speed for a ship of any size, was soon followed by the application of the turbine to various war-ships and other steamers. In war-ships the use of steam turbines has a special advantage in enabling the machinery to be kept at a low level, beneath the protective deck, in addition to the general advantages of reduced bulk, reduced vibration, reduced liability to break-down, and reduced consumption of coal and of oil which are common to vessels of all classes. The successful trials of the cruiser “ Amethyst" in 1904 demonstrated these advantages so conclusively that all new war-ships for the British navy, from battleships to torpedo- boats are being fitted with steam turbines. It is also used in many cross-channel packets, as well as in the largest ocean-going passenger vessels. The turbine-driven steamers "Lusitania ” and “ Mauretania" (1907) are the most powerful and the fastest ocean-going vessels afloat. The rapid development of the marine steam turbine makes it probable that it will displace the reciprocating engine in all large and fast ships. For slow-going cargo-boats it is at a disadvantage, unless gearing is resorted to, on account of the difficulty of securing a sufficiently high peripheral velocity in the turbine drums without making the turbines unduly bulky, and the leakage losses (due to steam passing through the clearance spaces over the tips of the blades) unduly large. Experiments by Parsons *(Trans. Inst. Naυ. Arch.*, 1910) on a ship in which a slow-running propeller is driven through reducing-gear from a high-speed turbine, have given highly promising results.

Enough has been said to show that the invention of the steam turbine is the most important step in steam engineering since the time of Watt. It is the first solution of the problem of using steam efficiently in an engine without reciprocating parts. The object in most steam engines is to deliver power to revolving machinery, and much ingenuity has been expended in attempts to devise engines which will produce rotation directly, instead of by conversion of reciprocating motion. No rotary engine, however, was permanently successful until the steam turbine took a practical form.

26. In the early development of the steam engine inventors had little in the way of theory to guide them. Watt had the advantage, which he acknowledges, of a knowledge of Joseph Black’s doctrine of latent heat; but there was no philosophy of the relation of work to heat until long after the inventions of Watt were complete. The theory of the steam engine as a heat engine dates from 1824, when N. L. Sadi Carnot published his *Réflexions sur la puissance motrice du feu,* and showed that heat does work only by being let down from a higher to a lower tempera­ture. But Carnot had no idea that any of the heat disappears in the process, and it was not until the doctrine of the conserva­tion of energy was established in 1843 by the experiments of J. P. Joule that the theory of heat engines began a vigorous growth. From 1849 onwards the science of thermodynamics was developed with extraordinary rapidity by R. J. Μ. Clausius, W. J. Macquorn Rankine and William Thomson (Lord Kelvin) and was applied, especially by Rankine, to practical problems in the use of steam. The publication in 1859 of Rankine’s *Manual of the Steam Engine* formed an epoch in the history of the subject by giving inventors a new basis, outside of mere em­piricism, from which they could push on the development of the steam engine. Unfortunately, however, it was assumed that the cylinder and piston might be treated as behaving to the steam like non-conducting bodies—that the transfer of heat between the steam and the metal was negligibly small. Rankine’s cal­culations of steam consumption, work and thermodynamic efficiency involve this assumption, except in the case of steam- jacketed cylinders, where he estimates that the steam in its passage through the cylinder takes just enough heat from the jacket to prevent a small amount of condensation which would otherwise occur as the process of expansion goes on. If the transfer of heat from steam to metal could be overlooked, the steam which enters the cylinder would remain during admission as dry as it was before it entered, and the volume of steam consumed per stroke would correspond with the volume of the cylinder up to the point of cut-off. It is here that the actual behaviour of steam in the cylinder diverges most widely from the behaviour which the theory assumes. When steam enters the cylinder it finds the metal chilled by the previous exhaust, and a portion of it is at once condensed. This has the effect of increasing, often very largely, the volume of boiler steam required per stroke. As expansion goes on the water that was condensed during admission begins to be re-evaporated from the sides of the cylinder, and this action is often prolonged into the exhaust. It is now recognized that any theory which fails to take account of these exchanges of heat between the steam and its metal envelope fails also to yield even compara­tively correct results in calculating the relative efficiency of various steam pressures or various ranges of expansion. But the exchanges of heat are so complex that there seems little prospect of submitting them to any comprehensive theoretical treatment, and information is rather to be sought from the scientific analysis of experiments with actual machines.

27. *Formation of Steam under Constant Pressure.—*In attempting a brief sketch of steam engine theory it is necessary to begin by giving some account of the properties of steam, so far as they are relevant. The properties of steam are most conveniently stated by referring in the first instance to what happens when steam is formed *under constant pressure.* This is substantially the process which occurs in the boiler of a steam engine when the engine is at work. To fix the ideas we may suppose that the vessel in which steam is to be formed is a long upright cylinder fitted with a piston which may be loaded so that it exerts a constant pressure on the fluid below. Let there be, to begin with, at the foot of the cylinder a quantity of water (which for convenience of numerical statement we shall take as 1 lb), at any temperature *t*0; and let the piston press on the surface of the water with a force of *p* lb per square foot. Let heat now be applied to the bottom of the cylinder. As it enters the water it will produce the following effects in three stages :—

1. The temperature of the water rises until a certain temperature *t* is reached, at which steam begins to be formed. The value of *t* depends on the particular pressure *p* which the piston exerts. Until the temperature *t* is reached there is nothing but water below the piston.

2. Steam is formed, more heat being taken in. The piston (which is supposed to exert a constant pressure) rises. No further increase of temperature occurs during this stage, which continues until all the water is converted into steam. During this stage the steam