by British electricians. In connection with telephony, enormous inventive thought has been given since 1880 to perfecting the mechanism of telephone exchanges, and the difficulties of automatic exchanges, which require no telephone girls or operators to effect the connection between subscribers, have now been finally overcome. Another very great advance has been in the "loading" of telephone lines. In 1887 Oliver Heaviside first showed the importance of inductance in the line as a remedy for "distortion" in the wave form of the speech currents, but it was not until Pupin, in the United States in 1899, suggested the insertion of inductance or "loading" coils at certain proper intervals in the line that practical success was obtained. A Danish engineer, Krarup, introduced a system of uniform loading for submarine telephone lines. The Pupin type of loading has made telephony possible over very great distances, such as New York to San Francisco, and Berlin to Rome. The difficulties of loading submarine cables up to 100 miles or so in length have been overcome. The theory of the subject has been treated by Heaviside, Kennelly, and Fleming.

Wireless telegraphy has attracted the attention of electricians since 1842, but no important invention was made until Marconi in 1896 first showed how to employ electromagnetic waves for this purpose, generated by a special form of Hertzian oscillator, and detected by an improved form of Branly metallic filings coherer. Lodge then demonstrated the importance of sympathy in connection with the subject, and it soon took very practical shape. Inventors all over the world were attracted to this new field, with the result that in a few years, chiefly by the work of Marconi and his co-workers, electric wave telegraphy between ships and shore became established as an indispensable aid to navigation. The construction of long-distance wireless stations, the first of which was erected at Poldhu, in Cornwall, in 1901, brought to notice many remarkable facts in connection with the propagation of long electric waves round the earth and through the atmosphere.

A very important factor in the recent developments of wireless telegraphy and telephony has been the invention of the thermionic detector and oscillator. The pioneer invention, according to judicial decisions, was made by the writer of this article in 1904 in applying for the first time an incandescent electric lamp with a metal plate sealed into the bulb as a detector of high-frequency electric oscillations. The "Fleming

valve" led to the invention of the three-electrode amplifier and thermionic generator of oscillations. This has given us an instrument of marvellous sensibility for detecting electric waves, and made wireless telephony a success and wireless telegraphy half round the world an achievement. The importance of wireless telegraphy and telephony in the European War of 1914-18 has been the cause of wonderful developments of the subject owing to the number of able minds brought to bear upon it.

Turning, then, from the present and the past and directing our gaze upon the future, we can certainly see many achievements looming before us. The world will be covered with long-distance wireless stations which will effect instantaneous communication over thousands of miles. Long-distance wireless telephony will enable speech to be transmitted over great distances, and it is quite within the bounds of possibility that the business man of the near future in London may hold a five-minutes' conversation with a friend in New York or even South Africa with as much ease as we now telephone to Glasgow or Liverpool. Directional wireless telegraphy will be used to steer passenger-carrying aeroplanes through cloud or fog. The steam locomotive and engine will gradually be replaced by the electric motor, and the water-power of the world will be utilised by its means. There are large possibilities still latent in connection with electro-chemistry and electro-metallurgy, and one great problem of the future is to tap the illimitable stores of energy latent in every chemical atom for the use and benefit of man. As coal becomes exhausted or coal power is made too expensive by labour difficulties, the question of new sources of energy becomes pressing. The engine of the future may be an improved form of internal-combustion engine in which the combustible is not coal gas or oil vapour, but some form of explosive compound in which atomic energy is suddenly released and expended in heating air or other gas in a cylinder.

Of one thing we may be perfectly certain, namely, that it is only through the avenue of pure scientific research sedulously and disinterestedly pursued that we shall reach the solution of these technical problems of supreme importance to mankind. The last fifty years has been a period of extraordinary technical applications of ever-increasing electrical knowledge, and no one can see reason to think that we have yet reached finality in the possible utilisation of this physical agent for ameliorating the conditions of human life.

DEVELOPMENTS OF MECHANICAL SCIENCE.

BY DR. W. C. UNWIN, F.R.S.

THE attempt here made to give a sketch of the mechanical side of progress in the last fifty years is necessarily slight. The year 1869 was the centenary of that in which Boulton and Watt took out their first patent for the steam

engine. It is due to the application of steam-power to industrial operations, more than to anything else, that there has been so great an increase of population, of wealth, and of social prosperity, and indirectly also of scientific knowledge, during

the last 150 years. Perhaps a review of some of the earlier advances already slipping out of knowledge, as well as of more recent and familiar discoveries, will be interesting.

Eighty years ago Dr. Lardner said it was due to the steam engine that reason had taken the place of force, the pen had superseded the sword, and that war had almost ceased on the earth. History does not confirm the prescience of this. The last war, largely an engineering war, owes its vast range and frightful devastation to means placed in the hands of armies and navies by mechanical science. To take one point, success in war depends chiefly on the rapidity with which large masses of men can be moved and served with ammunition and food. This must be accomplished by railways and motor trucks. At Verdun sixty million shells containing three million tons of steel were expended in thirty weeks.

During the last fifty years there has been a wide extension of research in mechanical science. Most large engineering works have their laboratory for testing materials, and the problems investigated are largely those suggested by industrial operations. This was specially important during the war, and it is now necessary to make permanent the more intelligent and active spirit thus aroused.

Hydraulics is a very old subject of research. Its problems are generally too complex for purely rational solution. Hence the need of continued experiment. A remarkable series of measurements of flow over weirs of different forms, under different conditions, with varying velocities of approach, and an investigation of the peculiar change of form of the water nappe on the weir crest at low discharges, was communicated by Bazin to the *Ann. des Ponts et Chaussées* in 1888-98.

In 1885 Froude gave the first direct determination of the frictional resistance of surfaces of different roughness in water (*Brit. Assoc. Report*). The most novel result was that the average friction per square foot depended on the length of the surface in the direction of motion. The friction of rotating discs was investigated by Unwin in 1880, and by Gibson in 1910. A research by Stanton and Pannell (*Trans. R.S.*, 1914) has shown the conditions of similarity of motion in fluids, and extended the results to water and air and to high velocities. These results have been of service in discussing the resistance of aeroplanes as tested in wind channels. Osborne Reynolds's experiments in 1882 showed that in flow-in pipes there was a critical velocity below which the resistance varied as the velocity, and above nearly as the square of the velocity.

Froude applied his results to the extremely important subject of the calculation of the resistance of ships. The greater part of the resistance is due to skin friction, and can be calculated on the assumption that the wetted surface is equivalent to a plane of equal area and length in the direction of motion and equal roughness. The remainder of the resistance, due to waves and eddies,

can be found by model experiments. There is an exact relation between wave and eddy resistance of the model and ship at corresponding speeds. The method of model tests of ships as a guide to design is now fully established. Sir Alfred Yarrow has generously established an admirable ship model tank at the National Physical Laboratory.

Water-power is one of the oldest sources of mechanical energy for industrial purposes. Its importance, looking to the fact of the limitations of coal supply and that in favourable circumstances it is cheaper than steam-power, can scarcely be over-estimated. Its use has greatly helped processes such as the fixation of atmospheric nitrogen, and the production of aluminium, calcic carbide, carborundum, caustic soda, etc., besides being an essential auxiliary in many great electric lighting installations. Thirty years ago no water turbine existed of 1000 h.p.; now turbines up to 20,000 h.p. have been made. The harnessing of Niagara, commenced in 1890, gave rise to a movement for utilising water-power on a great scale. The possibility of transmitting energy electrically to distances up to 200 miles, with little loss and commercial success, has greatly enhanced the availability of water-power. In the U.S.A. some seven million horse-power are utilised, in Norway more than one million, in Canada two millions, and in Italy one million. There are great possibilities in the British Dominions. In Canada and some other countries a Government survey of the water-power resources is in progress.

In 1869 the steam engine differed little from what it was as Watt left it, except in detail, size, and variety of application. One important modification since may be noted. Rankine and Clausius drew up a complete rational theory based on the mechanical equivalent of heat. But it appeared that actual engines used 40 to 60 per cent. more steam than was accounted for by the theory. In the late 'fifties Hirn, of Colmar, traced the discrepancy to the conductivity of the cylinder wall, which was cooled by evaporation to the condenser during exhaust, and then condensed part of the steam on admission. To remedy this he introduced superheated steam, used to some extent in the 'sixties with economical results, but not widely adopted until the 'nineties. Watt aimed at getting a dry, hot cylinder, but only partly succeeded. Superheating is a further step, only second in importance to the separate condenser.

The greatest change in the generation of power is due to the perfecting of the steam turbine by Sir Charles Parsons. The principle of the steam turbine is old, but it involved great scientific tenacity and courage and large, unremunerative expenditure before practical success was achieved. The first condensing turbine of 100 h.p. was made in 1892. Now in the latest cruiser, the *Raleigh*, there are turbines of 70,000 h.p. For large electric installations and for large and speedy ships the steam turbine has superseded the reciprocating

engine. Lately Sir Charles Parsons has introduced gear for reducing the necessarily high turbine speed to one more suitable for the propeller, and this will much extend the use of the turbine in marine engineering.

The development of the internal-combustion engine belongs almost entirely to the last half-century. On it has depended all aircraft and submarines, and most mechanical road transport. The first satisfactory gas engine was that of Dr. Otto in 1876. Dowson, in 1878, introduced producer gas, emancipating the engine from dependence on illuminating or town gas; and Benier soon after invented the suction producer. The Germans developed the large-cylinder, high-powered gas engine chiefly for utilising blast-furnace and coke-oven gas—a waste product. Sir Dugald Clerk, who has led the way in this country in developing the gas engine, and especially in studying its theory, estimates that there were gas engines of $5\frac{3}{4}$ million h.p. at work in 1909.

The first paraffin engine was that of Priestman in 1885. The Diesel oil engine, introduced in 1893, has perhaps the greatest thermal efficiency of any heat engine.

The petrol engine, which has made the conquest of the air possible, was greatly improved during the war, and is the lightest of heat motors. An aeroplane engine of 850 h.p. is stated to weigh only 1.63 lb. per h.p.

The future of air transport has very great promise, but it looks as if for commercial purposes the airship has advantages over the aeroplane. In coastal patrol and anti-submarine work naval airships carried out 9000 patrols covering $1\frac{1}{2}$ million miles. Engineers interested believe that an airship capable of carrying 1000 persons at 80 miles an hour is in reach of present practice. Attempts are being made to produce helium to replace hydrogen in the envelope, removing one source of danger.

Mr. Lanchester has reminded us that, with

Government help largely withdrawn, the aeronautical industry is in the position of a youth luxuriously brought up who finds himself face to face with the fact that he has to earn his own livelihood.

Structures and machines should be designed with adequate strength and at the same time with the least necessary material. In the old view the strength limit was the statical breaking weight, and the ratio of this to the working stress was termed the factor of safety. Wöhler's research in 1871 proved that, in ordinary conditions of continual variation of stress, fracture occurred with much less than the statical breaking weight, and depended on the range of variation of stress. Bauschinger showed that the position of the elastic limit changed with repetition of straining action, and that the range of elasticity appeared to be the same as the range of stress, which could be sustained indefinitely. Bairstow and Stanton have confirmed this. Osborne Reynolds constructed a machine in which continuous changes of stress in a test bar could be produced by the inertia of reciprocating weights.

In the period under consideration there has been a great extension of public and private mechanical testing laboratories. The National Physical Laboratory and the Bureau of Standards, Washington, are now Government institutions. In the U.S.A. very large testing machines have been constructed, several of 600 tons capacity, and one of 5000 tons at Pittsburgh. For testing full-size members such as bridge ties, reinforced concrete columns, etc., such machines are necessary. Though new tests of materials must be adopted with great caution, tests of hardness and tests of brittleness have been found useful. Guest, Scoble, and others have investigated compound stress, and found that in ductile materials the limit of resistance is the greatest shear stress. A very great advance has been made in the delicacy and accuracy of strain measuring instruments.

THE TREND OF MODERN METALLURGY.

BY PROF. H. C. H. CARPENTER, F.R.S.

METALLURGY is the art of extracting metals from their ores, refining them, and working them up into finished products for the use of mankind *at a profit*. The inevitable corollary of this is that the economic factor is always decisive as to the applicability or otherwise of any new scientific discovery which bears upon the industry. The art is one of the oldest in the world, but in spite of its highly diversified character and the profound influence that scientific methods have had upon its scope and technique, it does not differ to-day in essence from the ancient art except in the fact that to an ever-increasing extent the applications of science are found to be payable.

In attempting a survey of the present position
NO. 2610, VOL. 104]

and tendencies of the great metallurgical industries, only the broadest treatment is possible. Accordingly, no account will be taken of the usual subdivision of the subject into ferrous and non-ferrous metallurgy. Rather does there appear to be an advantage in omitting this distinction which has no scientific basis, but is purely one of custom.

The first stage in the passage from the mineral as mined to the manufactured metal is "ore-dressing," and here a very notable advance, made in the last few years, has to be recorded. The old method of "gravity" concentration, whereby the ore after being crushed was suspended in water and treated in a variety of machines for the concentration of the metallic contents, which,