HEROES OF SCIENCE.

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MECHANICIANS.

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PUBLISHED UNDER THE DIRECTION OF THE COMMITTEE
OF GENERAL LITERATURE AND EDUCATION APPOINTED BY THE
SOCIETY FOR PROMOTING CHRISTIAN KNOWLEDGE.

LONDON:
SOCIETY FOR PROMOTING CHRISTIAN KNOWLEDGE,
NORTHUMBERLAND AVENUE, CHARING CROSS, W.C.;
43, QUEEN VICTORIA STREET, E.C.;
26, ST. GEORGE'S PLACE, HYDE PARK CORNER, S.W.
BRIGHTON: 135, NORTH STREET.
NEW YORK: E. & J. B. YOUNG AND CO.
1884.

PREFACE.

THE present volume is but a small contribution to a large subject.

In the evening, when the stars begin to shine, there are only a few of them that catch the eye of the casual observer; but the careful watcher, who fixes his attention on them, is soon able to see them in all parts of the sky. After this manner the many heroes of mechanical science and art shine as the stars in the firmament. A slight study of any one branch of labour reveals worker after worker, whose sterling merit was attended with deserved success. A few names are known to the multitude, there are a multitude known to the few. Observers and recorders of their rising and setting have, however, been rare. Almost the only Astronomer who has examined a zone of these heavens is Dr. Smiles, the distinguished author of the "Lives of the Engineers" and of a volume of "Industrial Biography."

The present writer does not pass over, as unimportant, those mechanicians whom he has not named, nor ignore the departments of labour which are the field of their success; but he has been obliged to use the material that lay readiest to hand. No sooner had he undertaken to write this volume than he was unfortunately called to leave England for a remote part of the world, and his task has too much resembled that of the oppressed Israelites to enable him to complete his tale with satisfaction.

It is, however, worth while to endeavour to put into the hands of the boys of England the stories of *some* men whose example may stimulate them to that steady exertion which is preliminary to, and a prediction of, success in life.

LAHORE, 1884.

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INTRODUCTORY.

It is the aim of the mechanician to bring the great sources of power in nature under the control of man, so that they may serve his use and convenience in some new way, or more easily than before. The machines which he invents are his means of directing into desired channels of usefulness the energies which are always manifesting themselves in the gifts and movements of nature. These energies are the splendid heritage of the human race. In taking the sunshine and the rain, as they come to our fields, we enjoy but a small part of the possibilities of our patrimony. The mechanician developes the world's property, and thus adds to the power, wealth, and comfort of its inhabitants. By art he makes more of nature.

The simple sons of earth in the ages when the world was young, being well taught of brief experience, learnt not to regard the powers of nature as unmixed blessings, uniformly benevolent. They saw that they were capable of doing harm as well as good to the human race. They trembled before the destructive violence of a hurricane, of a tropical sun, of a raging sea. At other times these same powers, in more propitious mood, allowed them to bask upon a zephyr-fanned shore, and enjoy the warmth of a more genial sun. In their thought it would have been above nature, supernatural, divine, to influence these mysterious forces of the world. To still the storm, to calm the waves, to teach the sun any lesson of obedience, what man could accomplish so much? These seemed to them to be independent realities, endowed with a dread power that contrasted strikingly with man's feebleness; they were of a higher order of being, beyond his control, and he made of them gods to be feared, to be appeased, to be worshipped. Now, too, they are thus recognized and revered by the poor villagers of India in their simple worship of nature. These have their greater gods of fate, their Brahma, Shiva, Vishnu, Narain, whose names are heard seldom, and in infrequent ceremonies. But their lesser gods, who are not so immersed in affairs of universal importance that they cannot heed the wants of each humble suppliant, are constantly in their thoughts, and, though no temples are built for their worship, they are honoured by customary observances in the minute details of daily life. These are the sun, the river, mother earth, and water, deified, but not so transfigured as to be too bright and good to receive the constant petitions of the poor peasant. It is obvious to them by which of nature's agencies all the good things for which they toil are produced ; they see them always actively at work giving the increase when the seed is sown. How natural that they should offer prayer and praise to the powers directly concerned in blessing with fruit the very plot of ground which each one cultivates ! The sense of dependence how evident ; the suppliant disposition what a natural sequel ! How could poor mortals hope to win the favour of these great workers of weal and woe, how move them to beneficence, save by sacrifice, libation, and prayer ? Thus it was that the heroes of Greece set out on their distant adventures,

> "Hearkening the sounds borne from the lessening shore ;
> The lowing of the doomed and flower-crowned beasts,
> The plaintive singing of the ancient priests,
> Mingled with blare of trumpets, and the sound
> Of all the many folk that stood around
> The altar and the temple by the sea."

But they had learnt, however timidly at first, to put out their hands to use in some measure the forces which dominated nature. The wind and the wave were made subservient to man's wandering propensities; the ship and the sail were machines giving him the means of using for his own convenience some of the abundant energies which he found in the world. But when all was done he was more at their mercy than their master. Not for ages did he learn the first secrets of a power which could magnificently bend the forces of nature in prompt obedience to his will. As yet it is as though in our boldest advances we had but touched the skirts of a possibility once thought superhuman. Even from that touch a virtue has come out, transforming the whole world as by a magic might. The steam-engine and the work it has accomplished are everywhere, on sea and land. Who can calculate the actual amount of work done by the steam-engine in twenty-four hours? The world is full of resistances to human wishes, or we should live in a fairy land indeed. The steam-engine is busy daily in overcoming those resistances, and in placing within our reach the objects of our desire. This is its work. To this end all machinery is subservient.

The sources of available energy are those natural phenomena which give rise to any kind of motion in the world. The sun, the air, the soil, and rain combine to build up enormous forests and fashion beautiful flowers; this they accomplish the most part in their own way, free from the interference of man, except that he can exclude or concentrate the effects of one or other of these in particular cases. The lightning rends a tree, the storm uproots it; the tide daily lifts vast volumes of water. The earth itself by its very massiveness pulls powerfully to its surface all things animate and inanimate. Whatever does any work naturally can be compelled to work for man in some way by means of a machine. We make the earth swing the pendulums of our clocks; we make the tide lift our merchandise; we bid the wind work our windmills; the lightning is restricted to certain paths at our pleasure and for our purposes. The earth and air give up chemical constituents as we need them. The sun that floods the world daily with an inconceivable amount of energy has been made to work engines that can be employed in performing mechanical work.

But when we consider the extent to which these energies have been laid under contribution, we are obliged to own that man has yet learnt how to utilize only a trifling part of them. There is abundant room left for future inventors to use up more of the energies of sunshine, tide, and wind. Even in the case of coal we waste most of the energy which we attempt to use. It is demonstrable that a quarter of a pound of ordinary coal developes in burning enough heat to work a one-horse power steam-engine for an hour. Hitherto the world has had to be content with using from two and a half to four pounds of coal for this amount of work, simply on account of the small efficiency of the engines which have so far been invented. We are thus able to utilize but from one-tenth to one-sixteenth of the energy which we extract from our coal-fields for mechanical purposes. Our only hope for improvement is in the cunning of the mechanician. Truly, then, he deserves well of the world who invents a machine!

ERRATA.

Page 94, line 13, *for* "conditions" *read* "convictions.

" 102 " 24, *for* "was" *read* "were."

HEROES OF SCIENCE.

CHAPTER I.

THE FIRST STEAM-ENGINES.

AMONGST mechanical contrivances which have been devised to meet the wants of modern civilization, the invention of engines designed for the application of steam, as a working agent, is of first importance. The first of these engines was intended to meet the comparatively narrow needs of the "Gentlemen Adventurers in the Mines of England," and was very imperfectly adapted to this end. But improvements followed from time to time, and it was soon perceived that the successful use of the new motive force need be by no means restricted to mining enterprise, but that, wherever there was work to be done, steam might be made to do it under the intelligent control of man. The employment of steam-engines, stationary and locomotive, has given the world possibilities of work, of transport and of communication, which have been eagerly seized, which have resulted in rapid developments of industries, in vast increase of wealth, in additions to the comfort of life in all ranks of society, and in generally so altering the outward presentment of modern civilization as almost to create a new world, new in its wants, new in its surroundings, and still steadily advancing to other changes and to the subjection of other forces to its service.

The success of the steam-engine has been the reward of careful scientific thought, on the side of the practical application of science; and whilst being a reward it has also been an encouragement, and hence the material progress of the past century has reacted as a stimulus to intellectual progress, and has probably not been without effect on those branches of science which are at present purely abstract, for there is a close brotherhood between the thinkers who advance science on its practical and those who advance it on its theoretical side, and the interaction between them is beyond question. The common thought of men, too, has come under the influence which has so impressed its mark upon the age; men everywhere believe in the possibilities of progress with a firmer faith than would have been possible had they not—they and their fathers and grandfathers—been participating in new advances almost every few years of their life.

The steam-engine, then, merits our first consideration; and before we approach the stories of the life and work of Watt and Stephenson, the greatest names suggested by the mention of the steam-engine, and amongst the greatest which God has given England to boast of, we will briefly sketch its earlier history, when it was undergoing its first struggle for existence, and conforming itself gradually to the conditions imposed by its environment.

The first steam-engine which was the subject of letters patent was that of Thomas Savery; the patent bears date July 25, 1698; and this "engine to raise water by fire" was described by the inventor in a treatise called the "The Miner's Friend." In a letter addressed to the "Merchant Adventurers in the Mines of England," he says that his plea for coming forward as an inventor is that he had happily found out a new, but yet much stronger and cheaper, force or cause of motion than any before made use of. In the course of the letter he makes an observation which gives an idea (as Mr. Goodeve says in his "Text Book on the Steam-Engine") of the rude mechanical construction with which the world had fain content itself some one hundred and eighty years ago: "As for pump-making, that part of the trade will be much improved by my engine, for I must use board and timber for pipes, and have considerable employment for pump makers and carpenters for timber used about my engine. . . . For my design is not in the least to prejudice the artificers, or, indeed, any other sort of people, by this invention, which, on the contrary, is intended for the benefit and advantage of mankind in general."

Thomas Savery was of an old Devonshire family, and was born at Shilston, near Modbury, about the year 1650. His inclination may be supposed to have led him to adopt the engineering profession, and he became a military engineer. In the course of his careful and thoughtful study of mechanics and physical science, he became the author of several inventions, and he was himself well able to construct ingenious and difficult pieces of mechanism. His first patent was obtained for a machine for polishing plate glass. He afterwards occupied himself on a rowing machine for ships, to be worked by human labour—really, a pair of paddle wheels, set in motion by a capstan in the centre of the vessel. As may be said of most inventions, this was the fruit of much thought and anxiety, and the preliminary experiments were "at great charge." Owing, as Savery averred, to official jealousy, this, which was for a long time his pet invention, and which was regarded by him as of great importance on account of its giving the possibility of motion to ships in a calm, was not favourably received by the Admiralty; nor did it seem to commend itself to the general public, although a yacht fitted with the apparatus was able to distance all other vessels when tried on the Thames in the presence of thousands of spectators.

His next endeavour was to discover some effective contrivance for draining the Cornish mines, in which the water had always placed vast difficulties in the way of mining enterprise, and now threatened its last vital spark with extinction. This led him to the invention with which we are immediately concerned. The use of steam, as a working power, had already suggested itself to various ingenious philosophers, but their attempts to reduce their idea to a practical shape were clumsy and uneconomical, if not ineffectual, and furnished ample proof that the problem was not to be solved without long and careful thought. It was something, however, to have suggested methods of making steam do work under any the most favourable conditions; from such small beginnings it was possible to advance by stages of gradual improvement, until at length the use of steam, as a motive power, is not only possible, but has the commendation of economy, of might, and of docility beyond the most imaginative expectations of those early days.

Savery devoted several years to the subject before success rewarded his efforts. "Though I was obliged," he says, "to encounter the oddest and almost insuperable difficulties, I spared neither time, pains, nor money till I had absolutely conquered them." His own account of his discovery, according to Desaguliers, was that, having drunk a flask of Florence at a tavern, he flung the flask on the fire, and afterwards, having called for a basin of water to wash his hands, he observed that the little wine remaining in the bottom of the flask had turned into steam. Removing the flask from the fire he plunged it upside down into the basin of water; this suddenly condensed the steam, a vacuum was partially formed, and water was sucked up from the basin into the flask. This looks more like an experiment to test a suggestion which had previously occupied his thoughts, than the first rise and beginning of the notion in his mind; but at any rate the phenomenon was enough to indicate a method which might be useful on the large scale of raising water from the flooded depths of mines; and the suggestion was embodied in his invention. This, which is really the principle of the barometer, would, however, only have sufficed to raise water through a height of thirty-three feet at the outside, and had to be supplemented in some other way. The method chosen was similar to that which De Caus, at the beginning of the seventeenth century, had employed in a toy steam-apparatus, whereby a small fountain was made to play by the pressure of steam on the surface of water in a covered boiler. Accordingly, Savery made use of two principles. In the first place, the principle of the barometer, as shown in the experiment with the Florence flask, was adopted; a receiver containing steam was cooled, and a partial vacuum formed in it by the condensation of the steam; water was then forced into it from a lower level by atmospheric pressure, through a pipe and clack valve opening upwards as in the common pump. Then came the application of the "new force or cause of motion;" steam was again admitted to the receiver from a boiler, and its pressure forced the water to a still higher level through a similar clack valve and pipe against the pressure of the atmosphere, and by a mode of action identical with the former. The receiver was then once more cooled, and the process repeated.

This first application of the new force was most wasteful; the heat expended in alternately heating and cooling the receiver being lost to all useful purposes; experience, directed chiefly by the genius of James Watt, has shown that it is not necessary to pay the price of this enormous expenditure as wage for the services of the new servant. A trial of Savery's engine was made at Manchester in 1774, and is recorded by Smeaton; a modern pumping-engine will raise ten times as much water through the same height, with the consumption of the same amount of coal. The engine was also inadequate for draining mines of any depth, on account of practical difficulties of construction not at that time surmounted. Water could be raised into the receiver through a height of some twenty feet by atmospheric pressure; to raise it every additional thirty-three feet would require an internal pressure in the boiler exceeding by fifteen pounds on the square inch the external atmospheric pressure, apart from what would be required to overcome loss by cooling, condensation, and friction; the practical difficulties then in the way of constructing boilers sufficiently strong for this purpose were fatal to the success of the engine in ordinary mines. Mr. Bramwell, in his "Lectures on the Steam-Engine," remarks that it is by no means surprising that the mechanical skill and appliances of the time were unable to cope with the demands made upon them, and that pipes, joints, and cocks leaked and gave way, so that it was impossible to make for the mines a good working engine after Savery's model.

On one occasion, at Broadwaters, near Wednesbury, where he had erected an engine to drain a coal-mine, he continued to increase the pressure of steam to get the required forcing power, with the effect that the steam "tore the engine to pieces; so that, after much time, labour, and expense, Mr. Savery gave up the undertaking, and the engine was laid aside as useless." *

The failure arose not from a fault in the conception of the engine, but from the impossibility, at that time, of making the various parts sufficiently strong. Savery's own remedy was to use several engines at different depths for lifting the water from one to another, in succession, of a series of reservoirs; but the expense and the clumsiness of this device is apparent.

About Savery's later life we know very little beyond a list of appointments that he held at dif-

* Dr. Wilkes in Shaw's "History of Staffordshire," quoted by Smiles.

ferent times, chiefly through the patronage of Prince George of Denmark, to whom he dedicated his translation, in folio, of Cohorn's celebrated work on fortification. We have a portrait of him, which shows him to be a grand, stately gentleman of the time of Queen Anne; an ornament to society as well as to his profession. He died in the year 1715.

Meantime there were others at work with the same object. There lived at Dartmouth an ironmonger, Thomas Newcomen, who must have heard of Savery's invention, and may possibly have been employed to assist in the construction of one of his engines. At any rate, in some way or other, he was led to consider how steam could be employed to raise water from mines, and the result of his thought was the invention of a machine on a totally different principle, and capable of working with some success. About Newcomen's personal history but little is known; he was a man of strong religious feeling, and was accustomed to devote his leisure largely to religious teaching and preaching; pictures still show the quaint house in Lower Street, Dartmouth, where he lived and worked as a blacksmith, and where he thought out his sermons for his Baptist congregations. When he had heard of the proposed employment of steam to drain mines, his mind seems to have been put on the alert to discover some new and better method of accomplishing the same end by the new agent. We can fancy him sitting in cogitative mood at his own fireside, and observing that same agent actually at work in the tea-kettle before him, raising and dropping the lid perpetually, as the process of boiling was going on. This fancy is at least consistent with the story of him that used to be current in Dartmouth. If a piston could be made to rise and fall regularly by the successive formation and escape of steam beneath it, the piston might be connected by a rod with one end of a beam, with a fixed centre; the beam would, in consequence, swing up and down, and if the rod of a pump were attached to the other extremity of the beam, the pump would thus be regularly worked and water raised as required. The development of this idea is embodied in Newcomen's engine. Savery's engine sucked the water up into the receiver, the very place of action of the steam. Newcomen limited himself to obtaining regular motion from the action of steam, and that regular motion, when secured, he transmitted to a pump by means of a beam pivoted at its centre. He employed a vertical cylinder, into which the piston fitted as closely as could be; this was connected with the boiler below by a pipe that could be opened or shut by a stop-cock; when the piston was at the top of the cylinder the stop-cock was open, and steam filled the whole space, the air that might have been there at first being thereby expelled through a valve designed for the purpose, and called the snifting valve on account of its peculiar noise; the stop-cock to the boiler was next closed, and the supply of steam cut off; another cock was then opened for a short time by an attendant, whereby a jet of cold water was injected into the cylinder; this at once condensed the steam and produced a vacuum; the pressure of the air on the upper and outer surface of the piston now so far exceeded the pressure on the lower and inner side that the piston was borne down, and therefore the pump rods at the other end of the beam were simultaneously raised. The steam was readmitted, and its pressure being nearly equal to that of the atmosphere, the weight of the pump rods was enough to make them descend, and the piston ascend to its original position; the process being repeated, the pump was thereby worked. Arrangements were made for carrying off from the cylinder the injection water, and that produced by condensation of steam. On account of the fact that the work of raising the pump rods and the water in the pump during each stroke of the piston was done by the pressure of the atmosphere, Newcomen's engine was also called the atmospheric engine. Many of the minor details of the machine were after-thoughts—suggestions of experience; but it is unnecessary here to trace the development of the engine through its successive stages.

It takes much longer time for us to describe than for the engine to perform its action during one stroke of the piston. The fourth engine of the sort that was made was erected at Austhorpe, near Leeds, in 1714; it made about fifteen strokes a minute. A man and a boy were needed to attend to the engine; it was the business of the boy to turn the stop-cocks, as required. One improvement in its mechanism has earned immortality for the boy to whom it was due. A lad, called Humphrey Potter, who was employed to mind the stop-cocks, so connected them with the oscillating beam above that they opened and closed automatically at the right time, and released him to the games that were dearer to his heart. His first rude invention for this purpose was afterwards greatly improved by others. Potter did not, however, sacrifice everything to play; he grew up to be an excellent workman, and was the first to introduce these engines into Hungary.

It is enough to say in praise of Newcomen's contribution to the solution of the difficult practical problem then before mining engineers, in the words of Mr. Goodeve ("Text-Book on the Steam Engine"), that his "engine, improved and altered, and remodelled by Watt, has yet remained, to the present day, as the representative type of a single-acting pumping-engine." For some sixty years it was the only available engine, and was everywhere used. Its great fault was the wastefulness with which it used up fuel, the alternate heating and cooling of the cylinder demanding an expenditure of heat for which there was no equivalent in work done. See how all permanent mechanical improvements tend in the direction of economy;

an invention does not survive on account of its ingenuity; if it proves to practical men "not worth the candle," it is left in darkness, is buried and forgotten.

Newcomen is supposed to have lived a quiet life, without reaping any advantage from his invention, and to have died at Dartmouth about the middle of last century. From him we pass to James Watt.

CHAPTER II.

JAMES WATT.

"I look upon him, considering both the magnitude and the universality of his genius, as perhaps the most extraordinary man that this country ever produced; he never sought display, but was content to work in that quietness and humility, both of spirit and of outward circumstances, in which alone all that is truly great and good was ever done."—WORDSWORTH.

THERE is something peculiarly substantial about the fame of our great English inventors. Unquestionably it is not of that flimsy sort which is held together by the threads of a national or personal vanity. Other nations have their poets, painters, and musicians, whose excellence so preoccupies them that they will sometimes scarcely listen to the praise of ours. But all join in praising our inventors, in word, and most practically in deed, by adopting their contrivances. A poet may possess in high perfection all the qualities of his art, yet he must appeal to individual tastes, and his greatness will almost certainly be brightest seen where it kindles the flame of national pride. Our judgment of his merit must be affected as our mental bias accords with his or is out of sympathy with it. The work of a successful inventor, on the other hand, appeals to one universal bias, which dominates all peculiarities of character, which is human, not national, the bias of self-interest. In the struggle for success which is going on all over the world, no one, out of national jealousy or eccentricity of character, can afford to dispense with the steam-engine in its many applications. We thus have a universal verdict, and an impartial; for each invention is strictly judged on its own merits, is perpetuated if useful, rejected if it does not in practice serve its purpose. This is a realization, in the world of mechanical progress, of Goethe's dream, the consummation he so devoutly but vainly wished in the region of literary and artistic achievement. Here there is one standard which is universally acknowledged. All civilized nations constitute one vast confederation eager to apply to the general good, and to mark with the stamp of the world's approval, whatever invention may be worthy this recognition. Poems and music may pass comparatively unheeded, however extraordinary their merit; for it does not directly appear to be so much to one's interest to become acquainted with the best poetry or music as it is to take advantage of the best machines. And even if this were clear, the interests of different people and peoples would not be so identical as they are when the question at issue is narrowed down to the efficiency of rival machines. When the conflict is simplified to this degree, the fittest survives; and the survival becomes a true verdict of the fitness.

In his essay on Wordsworth, Matthew Arnold expresses the opinion that the verdict of such a confederation of civilized nations, were it possible, bound together for intellectual and spiritual progress towards a common end, would constitute the very ideal of real glory, that glory which, in the language of M. Renan, has the best chance of being not altogether vanity. The work of the inventor is an essential part of the intellectual progress of the world; it is the sequel of previous intellectual successes whose results it hands on, advanced and adorned with new suggestion, to succeeding workers. To estimate its worth we have seen that the confederation, hopeless in literature and the arts, has a veritable existence. The verdict has been given in favour of our English inventors, and must be acknowledged to have brought them a glory which it would be difficult to rate too highly. For this glory is a just measure of worth in one department of mental activity, and is therefore no more vain than worth itself, which perhaps all men of healthy thought would make a first exception from the sweeping condemnation of all things as vanity.

Pre-eminent among our famous inventors, foremost of our great mechanicians, is the inventor of the modern steam-engine.

James Watt was born at Greenock on the 19th of January, 1736. His father was a successful shipwright and merchant of that place, of which he was one of the most prominent inhabitants. His mother is said to have been a beautiful woman, and a good housekeeper, with a strong sense of duty, who lived a "melodious life," with all she had of outer things at one with the harmony that reigned within. Greenock was at that time but in its infancy; at the beginning of the century it was a small fishing village, with a single row of cottages down by the beach, where men worked and women wept, and where some of the quieter joys of life's brighter side also found a local habitation. It was about 1730 when James Watt's father commenced business there; the little place had now grown into a custom-house port, and boasted a harbour from which the merchandise of Glasgow found its way to the other side of the Atlantic, but on a small scale indeed in comparison with the like transactions of to-day. In Mr. Watt's yard all sorts of woodwork required for house or ship were made, and from his stores almost any other want could be supplied; he had ventures, too, in rich argosies, and was a builder and contractor besides. His energy must have absorbed the chief part of the business of the little port of Greenock.

From early childhood James Watt was of a delicate constitution, and his feeble health kept him a great deal at home, so that he was unable to mix with other boys in the schoolroom or playground. As a boy he was unusually thoughtful and studious, and of unflinching sincerity and truthfulness in all his dealings; the intense interest that he naturally took in acquiring knowledge of things about him prevented his mind from lying idle, even though he was without the stimulus of competition and the excitement of rivalry, those powerful goads to exertion. He was born, not made, a student. From the beginning he instinctively assumed that the mysteries and the truths of natural phenomena were capable of being partially at least understood, and he set himself to understand them with all the eagerness which others bestow on the solution of a puzzle, or the answer to an enigma. The highest attainment is truth, and the best of all endowments is the faculty for pursuing truth with dauntless determination till it is found; this faculty manifested itself even during the thoughtful boyhood of James Watt, and its success rewarded his later years. We are told that "from an early age he was remarkable for manly spirit, a retentive memory, and strict adherence to truth; he might be wilful or wayward, but was never insincere. His faults were acknowledged with candour, and, when quarrels occurred with his young friends, his father said, 'Let James speak; from him I always hear truth.'"

In course of time he was sent to Mr. M'Adam's commercial school, but his frequent ailments made his attendance there very irregular; nor did he much enjoy the experience, for there was in him neither the spirit nor the bodily strength to enable him to take part in the sports and adventures of his schoolfellows, by whom, indeed, he was in consequence regarded with ridicule and treated with contempt. Nor, notwithstanding his studious nature and his intellectual precocity, did he distinguish himself in his classes, but was thought to be rather a dull boy; this may be due to his having a bad verbal memory, or to his inability to bring himself to learning things by rote without trying thoroughly to think them out for himself; he may not have been advancing so rapidly as his classmates, but more surely because more slowly. No doubt the ill-health that often kept him at home for many days together was a considerable drawback to his success at school. When, however, he was put into the mathematical class, at the age of thirteen or fourteen, he found the work that suited him, and soon displayed a special aptitude for it. He continued his studies at the Greenock Grammar School, and seems to have left the dulness of his early school life behind him at Mr. M'Adams' establishment, for he now made fair progress in the rudiments of Latin and Greek, as well as taking the lead in the mathematical class.

His studiousness is shown by the fact that he read almost every book he could procure, and somewhat later, when a friend suggested that he should be more careful in his choice of books to read, he replied that he had never found one from which he had not gained some information or amusement. But, though he thus liked to know a little about everything, he did not content himself with merely superficial knowledge; he wanted to know all about something, and it was on natural philosophy, chemistry, and anatomy that his deeper thoughts were most concentrated; from the age of fourteen he diligently read and studied works on these subjects. It was about this time that he is said to have incurred that memorable rebuke from his good aunt, Mrs. Muirheid, who may well be pardoned for judging him by appearances, or at any rate for not seeing all that there was beneath the surface of his apparently idle play. The words that have been put into her mouth by the biographers of Watt have evidently been amplified to include a full description of the conduct that she was censuring, a description that would have been superfluous and unnatural in speaking at the time to the boy himself: "James Watt, I never saw such an idle boy: take a book or employ yourself usefully; for the last hour you have not spoken one word, but taken off the lid of that kettle and put it on again, holding now a cup and now a silver spoon over the steam, watching how it rises from the spout, and catching and connecting the drops of hot water it falls into. Are you not ashamed of spending your time in this way?" Although we cannot help regarding the descriptive part of this utterance as being intended for the benefit of the reader more than of the boy supposed to be thus addressed, yet the facts indicated and the reproof given may be accepted as historical. If this had been an hour's pastime of a boy habitually thoughtless and idle, it would not have merited a very severe rebuke, for from it he would have become acquainted by observation with some of the common facts of nature, in which he was evincing some interest, whether puerile or not; but no doubt James Watt was puzzling his brain in at least trying to understand the phenomena he was observing, or he was conducting an experiment to verify or illustrate some statement he had been reading in S'Gravande's "Elements of Natural Philosophy"—a book which he had read twice before he was fifteen years of age. He needed the rebukes of authority as little as the competition of companions to stir him up to mental activity, being impelled by a mightier principle within. He probably the rather needed some restraint in his studies, for he ran a risk of further enfeebling his weak constitution by too intense application to them. He suffered much from violent headaches that affected his nervous system and left him for days—even weeks—languid because for a time deprived of his wonted power, and depressed at being obliged to forego his wonted activity; if at these times he was gloomy and morose we can scarcely wonder; but when he was himself again and surrounded by his intimate friends, he was ever the brightest and happiest of companions, and full of varied conversation, showing on such occasions throughout his life

> "Heart affluence in discursive talk
> From household fountains never dry;
> The critic clearness of an eye,
> That saw through all the Muses' walk;"

with always "high nature amorous of the good."

At home in his father's workshop and yard he was always busy in some way or other; he learnt to use many tools and instruments with great dexterity, so that the journeymen were accustomed to say that "little Jamie had gotten a fortune at his fingers' ends." He had a small forge set up for his own use, and occupied himself in making and repairing tools and apparatus in use in the trade, so that he attained to considerable excellence as a workman; for here, as in everything, whatever he did he liked to do thoroughly. These two characteristics, his aptness for mathematical reasoning, and his carefulness in the use of tools, were the foundation of his future fame. His practical experience of the principles of mechanics, thus early gained, was of incalculable advantage to an inventor who was always on the watch to distinguish in his contrivances "what must be, and what may yet be better;" to submit to the one, and to perfect the other.

For his recreation he delighted to wander in solitude amongst the lochs and valleys in the neighbourhood, indulging in some happy tone of meditation between some fancy coming and some fancy gone. He thus developed a taste for the botany of wild flowers, and for geology which essayed to account for the wild and fantastic aspect of rock and hill and loch. But his rambles were in the night time too, and he was chiefly attracted by the impressive mechanism of the skies; this taste for astronomy was encouraged by his easy access to nautical instruments at home, "for it was a peculiarity which characterized him through life that he could not look upon any instrument or machine without being seized with a desire to understand its meaning, to unravel its mystery, and master the rationale of its uses." He was fond, too, of hearing stories, and was himself a capital story-teller. Mrs. Campbell, of Glasgow, with whom he stayed during one vacation for change of air, related how that every evening, before retiring to rest, he contrived to engage her in conversation, and then began some striking tale, and whether humorous or pathetic, the interest was so overpowering that the family all listened to him with breathless attention, and hour after hour struck unheeded. In his wanderings in the country round Greenock he enjoyed entering the cottages of the peasants, and picking up the tales and legends of their folk lore. Fishing was also an occupation in which he took pleasure.* Thus this fragile

* At this time salmon were so abundant in the Clyde that the Glasgow servants and apprentices were accustomed to stipulate that they should not have salmon for dinner more than a certain number of days in the week. This is also said to have been formerly the case in London.

Greenock lad lived a varied life, and attached himself by the clinging fibres of eager interest to every branch of knowledge within his reach.

But he had to leave his home with all its loved occupations, and repair to Glasgow, in order to learn a trade; this step was made the more imperatively necessary owing to a succession of serious reverses in business experienced by his father, including the foundering of one of his ships at sea. Accordingly when he was about eighteen years of age he went to Glasgow, and spent a year there with his mother's relatives, the Muirheids; and in face of the immediate prospect of having to depend on his own resources for a livelihood, he naturally and without hesitation chose to devote himself to learning the trade of a mathematical instrument maker.

Glasgow was not then the large and important place which it has since become; its chief and almost its only important merchants were the "tobacco lords," who imported tobacco from the plantations in Virginia, and thereby brought no inconsiderable wealth to the place. The sole assistance Watt could obtain there in his chosen business was from a mender of things in general, who called himself an "optician;" but from him there was nothing to be learnt, although Watt stayed with him a year and made himself useful in repairing instruments and dressing salmon flies. The town was also the seat of a flourishing university, and could boast some able and renowned professors. If one were a Scotchman, he could scarcely help being proud of the fact, when he remembered the national love of education and of learning, and the habitual earnestness of character which have long distinguished the hardy Scotch people. Watt does not seem to have gained much from his proximity to the precincts of learning, beyond an introduction to Dr. Dick, the Professor of Natural Philosophy, who was quick to discern his ability and ready to encourage so promising a student, for this he soon perceived Watt to be. It was largely on his advice that Watt, after spending a year in Glasgow, determined to proceed to London to acquire the best possible instruction in practical workmanship, in which he was ambitious to excel.

The journey to London had to be undertaken on horseback, for there was not even a stage-coach from Glasgow to London in those days; this involved twelve days' travelling, and he reached London on the 19th of June, 1755. He found great difficulties in the way of obtaining the instruction he needed, from the fact that, by the rules of the trade, he would be expected to bind himself as an apprentice for seven years; he could not even work as a journeyman without having served that length of time. Now he desired to learn all he could in as short a time as possible, and then to return to Glasgow and set up business on his own account. A fortnight after his arrival he wrote to his father, "I have not yet got a master; we have tried several, but they all make some objection or other. I find that, if any of them agree with me at all, it will not be for less than a year; and even for that they will be expecting some money." At last he succeeded in coming to terms with Mr. John Morgan, a respectable mathematical instrument maker in Cornhill, to receive instruction in the work of the trade for one year, and, in return, to pay the sum of twenty guineas, and to give his labour in the business. Then he went to work in earnest, and he recounts with honest pride how he had made a brass parallel ruler eighteen inches long, a brass scale of the same length, a Hadley's quadrant (better than his master's apprentice who had been with him two years), a pair of azimuth compasses, a brass sector, a theodolite, and other instruments of the most accurate sort. In a half-year he felt that he had acquired more knowledge and skill than apprentices were used to gain after a seven years' apprenticeship; and when his year was up he wrote —"I think I shall be able to get my bread anywhere, as I am now able to work as well as most journeymen, though I am not so quick as many."

The perseverance with which he gave himself to his work, and the elements of encouragement furnished by his sense of progress, tended to make him cheerful, notwithstanding his very bad health and the privations to which his poverty obliged him to submit. In the shop he was exposed to draughts, and caught a severe cold, ending in a racking cough and rheumatic pains which did not cease to trouble him for years after. Knowing that any expense in which he indulged would be a perceptible drain on his father's purse, he lived in the most frugal manner, and wrote home to say that he could not reduce his expenses further without "pinching his belly." At the same time he stood in some danger from the press-gangs which were wandering about the Metropolis, seeking whom they might devour. There were as many as forty of these at work, who seized all the able-bodied men they could lay hands on. Perhaps Watt's constitutional weakness would have made him a prize not worth their taking for service in the army or at sea, but this did not diminish his anxiety or put him at ease on the subject. Had he been a prentice or a creditable tradesman within the liberties of the city, he might have had the protection of the Lord Mayor's Court, but if he were carried by a press-gang before the Lord Mayor he could not avow that he wrought in the city, it being against the laws for any unfreeman to work even as a journeyman within the liberties; and so in hurrying to his lodgings from his day's work he felt himself in considerable jeopardy. Thank heaven, he escaped.

But neither mental alarms, nor bodily weakness, nor the repressive hand of poverty were able to induce in him indifference to the great object he had in view in coming to London. His steady pursuit of excellence in the work he turned out—

what was it but the expression of that genius within him which obliged him to press on without haste and without rest in assured progress?

James Watt was now a skilled workman, and as such he returned to Glasgow in search of employment in the autumn of 1756. Trade jealousy prevented him opening a shop on his own account, for he was neither a burgess, nor had served an apprenticeship in the borough, and it was mainly through the influence of his friend, Professor Dick, that he obtained any work. The university had just received from Jamaica a valuable collection of astronomical instruments, bequeathed by Mr. Alexander Macfarlane, and as they were somewhat out of repair, and had besides suffered from the effects of sea-air, Watt was asked to undertake the cleaning and refitting of them, for which job he received the sum of five pounds sterling. Some six months later the university came to his rescue in a still more effective way by assigning to him an apartment and shop within the precincts of the College, within which trade jealousies dared not intrude, and conferred on him the title of Mathematical Instrument Maker to the University. His work at the Macfarlane instruments thus stood him in good stead; it had been performed with thoroughness and ability, because these were natural to the workman, James Watt, and the very habit of his soul; but whilst busy with these he did not see that he was working out his own testimonial for university support, and that the one escape from his present perplexities would be secured by the excellence of his work; even if he had been prompted by such a hope he could not have improved on his performance, simply because he had, as usual, done his best. It was for others to recognize his merit and devise a reward, it was for him to aim not at a reward, but at perfection.

It was not immediately, however, that his business assumed a successful and profitable aspect university *protégé* though he was. Almost the only remunerative work he could find was the making of Hadley's sextants or quadrants, of which he could turn out three a week with a profit of some forty shillings; but there was difficulty of disposing of them in Glasgow, which was then inaccessible to sea-going ships, and he was obliged to send them to places further down the river for sale, and even contemplated a journey to Liverpool or London to obtain orders for them. Some years before, his uncle had made a careful survey of the river Clyde, and Watt, in the dearth of other employment, now published the map of the river, which had come into his hands on his uncle's death. As far as appearances went his business prospects were only a little more promising than those of Solomon Gills at the sign of the Little Midshipman in Dickens' story of "Dombey and Son;" his want of success could never, however, have been attributed to the world's having hurried past him in the press of competition, new invention, alteration, leaving him a long way behind on its track. It was not competition, but the want of it, that made his outlook discouraging. He even thought of giving up his business, and taking to some other.

As time went on he gradually acquired further fame for his skill in constructing complex philosophical instruments, and was at length entrusted with the repairing of almost anything and everything that was out of order. Although he had no ear for music, he succeeded admirably in mending a number of musical instruments, and even in constructing them, during the course of which work he interested himself, with the concentration of genius, in the science of acoustics, upon the principles of which his success depended. He contrived a machine for drawing in perspective. Any leisure that he still had he devoted to chemical and other experiments, and to reading and studying books of all sorts from the college library, which was open to him. He is said to have given vent to some of his surplus energy by writing tales and verses, but none of his attempts have survived. His work brought him into contact with the professors, who had to employ him to make apparatus for their experiments, and they found him to be, as Dr. Black, the Professor of Medicine and Lecturer on Chemistry (famous in connection with the discovery of latent heat), said, a young man possessing most uncommon talents for mechanical knowledge and practice, with an originality, readiness, and copiousness of invention which often surprised and delighted them in their frequent conversations together. The same professor proceeds to say, "I also had many opportunities to know that he was as remarkable for the goodness of his heart, and the candour and simplicity of his mind, as for the acuteness of his genius and understanding. I therefore contracted with him an intimate friendship, which has continued and increased ever since that time." Dr. Robison, who afterwards became Lecturer on Chemistry in the University of Glasgow, availed himself in the same way of the privilege of companionship and friendship with Watt, and left a record similar to that of Dr. Black's. Instead of a workman for them to direct, he soon became an authority for them to consult, and these and other professors and students had frequent conversations with him on mechanical and philosophical subjects of common interest to them. So great a reputation did he acquire that hardly any projects, such as canals, deepening the river, surveys, or the like were undertaken in the neighbourhood without consulting the mathematical instrument maker, and he was even asked to take charge of some considerable works of this kind, though he was as yet wholly inexperienced in them. The fact was he was everywhere trusted as a man who would do well anything he consented to do at all.

In 1763 he married his cousin, Margaret Miller, to whom he had long been closely attached. Another cousin, Mrs. Marion Campbell, says she considered it as having added to his enjoyment of life, and as having had the most beneficial effect on his character. "Even his powerful mind sank occasionally into misanthropic gloom, from the pressure of long-continued nervous headaches, and repeated disappointments in his hopes of success in life. Mrs. Watt, from her sweetness of temper, and lively cheerful disposition, had power to win him from every wayward fancy; to rouse and animate him to active exercise. She drew out all his gentle virtues, his native benevolence, and warm affections."

We have now reached the critical period in his life's researches; it was at this time that he became absorbed in the study of the steam-engine, and was bending all his powers to remedy its imperfections, which showed themselves to his keen perception more clearly than they had ever been seen before. The story of his work places him before us in as high a rank amongst physicists and philosophers as amongst mechanicians; his invention was no mere happy mechanical suggestion, but was the intelligent practical application of scientific truths first demonstrated and understood by himself. It was possibly Robison who was the first to direct Watt's attention to the subject of the steam-engine; at any rate the two friends had a conversation on the subject in 1759, when Watt admitted that he was absolutely ignorant of it. After this his attention was constantly reverting to the steam-engine. Being a practical man, he was anxious to see one for himself; but only one had hitherto been erected in Scotland, namely, at the Elphinstone Colliery, in Stirlingshire.* He heard, however, that there was, belonging to the Natural Philosophy class in the university, a model which had been sent to London to be repaired. There was great delay about its return, and Watt suggested to Dr. Anderson, the Professor of Natural Philosophy, that the university should if possible get possession of it again; at some cost its restoration was effected, but it does not seem to have undergone any repairs during its absence. Before it arrived Watt had been reading with great diligence all that there was for him to read bearing on the subject of the steam-engine, and had conducted several experiments to try the power of steam, and its usefulness in doing work. The small model came into his hands in the winter of 1763–4.

We will attempt to follow his work with this model. He found, when he set it in motion, that the boiler could not supply steam in sufficient quantity to drive the engine for more than two or three strokes of the piston successively; he therefore attempted to increase the generation of steam by blowing the fire, but even this was unavailing. Being unable to generate steam enough for the working of the engine, he thought it best to see whether the engine's demand for steam was not excessive, and, for this purpose, to enquire how the

* A second was erected at the Goran Colliery, near Glasgow, about 1760.

steam was used up in the piston. The engine, as we have seen, consisted essentially of a cylinder fitted with a movable piston, with a valve or stop-cock for admitting steam from the boiler into the space below the piston; the steam by its pressure counterbalanced the external pressure of the air on the piston, and allowed it to be raised by the descent of the heavy pump-rods at the other end of a beam with a central pivot; the valve was then shut and cold water injected into the cylinder below the piston, the result of which was that the cylinder was cooled, the steam condensed to water, and the pressure below the piston reduced almost to nothing, so that the piston descended under the action of the atmospheric pressure and its own weight, which were more than sufficient to counterbalance the weight of the pumping gear at the other end of the beam. When the piston reached its lowest position the valve was again opened, and the process repeated itself as long as steam was supplied in sufficient quantity from the boiler. Watt was soon struck by the enormous waste of steam that this process involved, and waste of steam of course implied waste of fuel and the incurring of great unnecessary expense. He noted that after each descent of the piston, the heat of the steam supply had first of all to warm up the cylinder and piston themselves to a temperature such that steam could remain uncondensed in the space between them; that the first inrush of steam was really condensed in effecting this; in the second place, steam was needed to *keep* the cylinder at the same high temperature during the upward stroke of the piston, for of course its tendency was to get cooled down by radiating its heat out to colder things around; both of these tasks had to be performed by the steam in addition to the specific work for which it was sent into the cylinder, namely, to assist in raising the piston. To make a machine that would work without exacting an expenditure of steam for the first of these purposes it was necessary that the cylinder should be maintained always as hot as the steam that entered it; to avoid the second source of loss partially, the cylinder might be surrounded by some bad conductor of heat, such as wood soaked in linseed oil and baked to dryness, or the cylinder might be made of such material instead of brass or other metal; Watt's experiments on this head were unsatisfactory until he had already met the first difficulty, and then he saw that he might remedy this evil, not only partially, but absolutely, by surrounding the cylinder with steam at its own high temperature. Again, he was led to the conclusion that, in order to make the engine work satisfactorily, the steam should all be thoroughly condensed for the down-stroke; for this purpose it should be cooled below 100° F., otherwise a considerable amount of vapour would remain, which would impede the descent of the piston. This statement of the problem before him seemed to involve a physical impossibility, namely, that the cylinder should never be cooled below 212°, and that during every down-stroke of the piston it should be cooled to less than 100°. But it was something to formulate the difficulty; it showed him more clearly where it lay. Those were true words which Plato ascribes to Socrates, "Nothing is so clear that it does not admit of becoming clearer by being spoken."

Whilst trying to escape from the dilemma in which he was placed by these considerations, Watt carried on a series of experiments with a view to obtaining from nature direct an answer to many of the obstinate questionings that puzzled his mind. In the course of these he learnt that a quantity of water in the form of steam was able to raise six times the amount of cold water to the boiling point, *i.e.*, to its own temperature, merely by condensation, without altering its own temperature at all. This accounted for the large injection of cold water needed in the cylinder, but in addition to this it furnished a very material fact in support of the new theory of latent heat which had only a few months previously been propounded for the first time by Professor Black, but of which Watt himself seems either not to have heard or not to have heeded, probably owing to the great pre-occupation of his mind with the steam-engine.

It seemed worth while to enquire whether a practical improvement could not be effected by reducing to tolerable limits the waste of steam which was apparently inherent in the engine; for instance, by cooling the cylinder as little as possible, by diminishing the injection; but, as we have seen, a considerable injection was indispensable. Now the injection was needed to condense the steam and produce a vacuum; if the steam could be withdrawn in any other way, this injection and attendant cooling of the apparatus would be rendered unnecessary. Otto von Guericke had used an air-pump to withdraw the air from a cylinder fitted in a similar manner with a piston, but the process was of course slow, and could not be adopted in the steam-engine; it would have been easier, too, to work the water-pumps themselves than to have the labour of the air-pumps to perform.

Having essayed to trace the thoughts of the inventor to the verge of his discovery, we will allow him to complete the story in his own words. "Early in 1765 it occurred to me, that if a communication were opened between a cylinder containing steam, and another vessel which was exhausted of air and other fluids, the steam, as an elastic fluid, would rush into the empty vessel, and continue to do so until it had established an equilibrium; and if *that vessel* were kept very cool by an injection, or otherwise, more steam would continue to enter till the whole was condensed." This was his great invention of a *separate condenser* for the steam-engine, and enabled him to satisfy all the hard conditions which he felt to be imposed upon him by the necessity of making the engine work perfectly. Less than one quarter of the amount of steam was now used in doing the same amount of work by the engine, for he had found that in the old engine more than three quarters of the steam was condensed and wasted during the ascent of the piston. He could now, too, prevent the loss of heat from the cooling of his cylinder by placing it inside another vessel full of steam, or giving it a "steam-jacket," as he called it. Let us hear what he and his friends said about the discovery. Dr. Black wrote, "This capital improvement flashed on his mind at once, and filled him with rapture; and he immediately made a hasty trial of it which satisfied him of its value." Dr. Robison had been away from Glasgow for a fortnight, and on his return chanced to call on Watt, and began talking to him on the subject of their last conversation together—something about steam. Watt looked at him, and said briskly, "You needn't fash yourself any more about that, man; I have now made an engine that shall not waste a particle of steam. It shall all be boiling hot;—aye, and hot water injected if I please." Mr. Hart, a Glasgow tradesman, asked him many years after if he remembered how the first idea of his discovery came into his mind; he replied, "Oh yes, perfectly. One Sunday afternoon I had gone to take a walk in the Green of Glasgow, and when about half-way between the Herd's House and Arn's Well, my thoughts having been naturally turned to the experiments I had been engaged in for saving heat in the cylinder, at that part of the road the idea occurred to me that, as steam was an elastic vapour, it would expand and rush into a previously exhausted space; and that if I were to produce a vacuum in a separate vessel, and open a communication between the steam in the cylinder and the exhausted vessel, such would be the consequence."

The discovery was in the manner of it an apt example of what is called "a flash of genius." A moment's clear insight showed a way out of all difficulties, a sudden inspiration discovered a solution that was on the face of it the right one—but such a sudden inspiration as only comes, though it be in moments of relaxation, to men who have given long and weary thought to the subject in question, and who have thereby possessed themselves of an accurate and definite knowledge of the difficulties they must surmount; then, when the solution presents itself, they are in a position to receive at a glance the happy revelation of a complete success. We cannot wonder that Watt was filled with rapture at such issue to his labours; and can imagine that he must have felt

——"like some watcher of the skies
When a new planet swims into his ken;
Or like stout Cortez when with eagle eyes
He stared at the Pacific—and all his men
Looked at each other with a wild surmise—
Silent, upon a peak in Darien."

This comprehensive suggestion not only gave the means of fulfilling all the requirements which Watt had seen to be necessary, but it brought many new improvements in its wake; these, which were the result of one or two days' further work, Watt regarded as the natural fruit of his first pregnant idea that the cylinder should be kept properly hot and dry. For instance, he saw that the admission of cold atmospheric air above the piston to force it down was undesirable, because it must necessarily cool the cylinder in following the piston; he therefore replaced it by steam admitted from the boiler, the upper end of the cylinder being completely closed in; thus the engine was no longer atmospheric, but became the first real steam-engine, the first, that is to say, in which steam provided the working power. This, however, introduced the difficulty of making the piston fit closely into the cylinder, so that no steam should leak from one side to the other—a difficulty which Newcomen had overcome by letting a layer of water lie upon the upper surface of the piston, a remedy which was incompatible with the conditions to which the machine had to submit in the hands of its new master. It took much experimenting to determine the best remedy, but the use of fat and oil was finally adopted.

After the idea had taken perfect shape in the mind of the inventor, there were still other difficulties to be surmounted on the practical side before it could be embodied in a working engine; for in practical mechanics, perhaps more than in other regions of science and life, there is many a slip 'twixt the cup and the lip, many a brilliant thought that refuses to be trammelled with the trappings of usefulness, many a vision splendid that is destined to fade away without ever seeing the light of common day. In battling with these difficulties, in contriving expedients manifold, in testing his suggestions, in rejecting those that proved unmanageable and incorporating those that showed promise of good service, Watt spent several months and more than all his money; for mechanical experiment is an expensive pursuit, and meantime the more immediately remunerative occupation of instrument vendor had been laid aside for the sake of the engine. The work would have been arrested by poverty, that imperious and repressive tyrant, had not the assistance of some capitalist been available in the emergency. It was not easy to find this assistance, for the sum needed would probably reach to several thousands of pounds before the inventor could make, modify, and, perhaps, reconstruct his models to the point at which he could feel confident of their success; and, in addition to this, capital and position were required in order to make the engines and to introduce them to the public notice.

Dr. Black had already given Watt every encouragement and all the practical help he could afford, but he saw clearly the difficulties that hedged in the new invention, and it was due to his representations that Dr. Roebuck, of the Carron Iron Works, Borrowstoness, was at last brought to interest himself in the concern. He was an enthusiastic man, who had had considerable experience of steam-engines such as were then in use for draining-mines; he had tried them, and was just then finding them wofully wanting, so far as his own coal-pits were concerned. At first he showed much hesitation about embarking in Watt's venture, but he carefully discussed its merits, both with Dr. Black and with Watt, and finally decided to support it. This very valuable ally agreed to take Watt's debts upon himself, and to lay out whatever more money might be needed for experiments and for securing the patent, in return for which two-thirds of the property of the invention was made over to him. It was some time before Watt could get away from Glasgow; whilst there he vigorously continued his experiments. When he was able to go to Kinneil House, Dr. Roebuck's residence at Borrowstoness, a small engine was soon built there, and for three years an arduous and expensive series of experiments was carried on, at the end of which large experience had been gained of the advantages of different shapes of boilers and condensers, of the different materials of which they might be constructed, of devices for securing the air-tight working of the piston-rod, and the smooth and steady co-operation of the various parts. Finding his first bright hopes fairly confirmed by his experience with the machine itself, Watt proceeded in August, 1768, to take measures to obtain a patent.

Meantime, Dr. Roebuck had become entangled in serious financial difficulties; he was an enterprising man, but every project he took up seemed to turn awry from its straight purpose, and take the path to failure. He was a man "whom unmerciful disaster followed fast and followed faster," like the hypothetical owner of Poe's raven. He was now unable to carry out his agreement, namely, to defray the cost of obtaining the patent.

Probably on account of these impending troubles, Watt had already engaged himself in engineering work to a slight extent, and had, in 1767, paid a visit to London in connection with a project for a canal between the Firths of Forth and Clyde. He then passed through Birmingham and inspected the Soho Works, which had been erected by Mr. Boulton for the manufacture of metal goods of all sorts, and where the work was carried on with unprecedented excellence, and on an unprecedented scale. He was shown over the works by Dr. Small, through whom communications were opened up between him and Boulton on the subject of his steam-engine, whence there seemed promise of an escape from his embarrassments. When he came to England in the course of the next year, he stayed for a time with Boulton, who expressed a desire to be "concerned in the fire-engine." No steps could, of course, be taken with this object without consulting Dr. Roebuck, and with him the negotiations were long and tedious; but it was evident that nothing would have pleased Watt better than that his invention should be taken in hand and introduced to the world at the Soho Works, the place which of all others would give it the best opportunity of establishing itself in the public esteem. Indeed, it could not be doubted that the mere fact of Mr. Boulton committing himself to its success would be a strong testimonial in its favour; and besides, his workmen were the most skilled, and his processes the most perfect in the country, and the new engine might be irremediably damaged in public estimation if, owing to bad workmanship, the first examples of it were unable to compete favourably with those already in use. The importance of accurate and true workmanship in Watt's engine, and the difficulties which in consequence beset it, can scarcely be better illustrated than by the fact that the engineer Smeaton—who has been called the pioneer of modern scientific engineering—some years after the patent was taken out, doubted the practicability of getting the different parts executed with the requisite precision, and from the extreme difficulty of attaining this desideratum, augured that this admittedly powerful machine, in its improved form, would never be generally introduced. He thought that the saving effected by economical working would be more than counterbalanced by the great cost of manufacture if the workmanship had throughout to be of such unprecedented perfection.

Mechanical skill has made wonderful advances since those days, and it cannot be doubted that much of the improvement is due to the necessity of complying with the requirements of the newly invented steam-engine. The difficulty was not inherent in the machine, but in the fact that the necessary trained skill did not at that time exist; when the prospect of work and wages led to the requisite training, the development of the needed skill, and the invention of new and cheaper processes,* then of this difficulty it was demonstrated, as of many others, *solvitur ambulando.*

If for no other reason, the memory of Dr. Black would deserve to be held in high honour by us on account of his coming forward with the funds, which Dr. Roebuck was unable to provide, to enable Watt to take out his patent for "a new method of lessening the consumption of steam and fuel in fire-engines."

Fortified with this patent, which bears date January 5th, 1769, Watt returned with vigour to still further experiments at Kinneil House, in the hope that he would yet be able to prop up his friend and partner's tottering fortunes by the great success of his invention. But hope was again and again delayed, and Watt's marvellously fertile mind was busy with the most abstruse investigations bearing on each and every part of the engine, and he seemed never content to

* Instance: fifty years ago the cost of labour for making a surface of cast iron true—one of the most important operations in mechanics—by chipping and filing by the hand, was twelve shillings a square foot; whereas it is now done by the planing machine at a cost for labour of less than a penny. James Nasmyth, too, says that the forgings done by his steam-hammer were better and almost absurdly cheaper than those done by the old process.

leave it alone and allow it to take its chance as it was. He therefore saw that it would be best for Roebuck to make a bargain with Boulton, and to relinquish to him a share, at any rate, of his property in the invention, in return for some payment which he would find serviceable in the midst of his pressing difficulties. The arguments he employed in trying to bring this arrangement about show that he also saw therein the most favourable prospect for his engine; in fact, they were little more or less than pleas on its behalf, pointing out how much it suffered under their present want of means, and how much it would gain by connection with Mr. Boulton; his innate modesty compelled him to add as a final argument: "Lastly, consider my uncertain health, my irresolute and inactive disposition, my inability to bargain and struggle for my own with mankind; all which disqualify me for any great undertaking." At length, in November, 1769, Dr. Roebuck made an offer to Dr. Small and Mr. Boulton of one-half of his share, or one-third of the whole property of the patent, in return for such a sum, not less than a thousand pounds, as they, after the experiments with the engine should be completed, should think just and reasonable. Twelve months were given them to come to their final resolution. The negotiations, however, fell through, and shortly afterwards Dr. Roebuck found himself quite unable to withstand the difficulties of the commercial crisis which was then felt throughout Great Britain. Watt, in consequence, took refuge in engineering again, for he had by this time a family of three children dependent upon him, and must needs provide for them. Fortunately the Glasgow magistracy showed an absolute trust in his judgment and engineering ability, and gave him frequent employment in the more important municipal works; his reputation grew with his every undertaking, work flowed in apace, and leisure for his loved experiments was seriously curtailed. His first engagement was in the construction of the Monkland Canal, for bringing coals by water from the collieries at Monkland, in Lanarkshire, to within a mile of the city of Glasgow; it occupied him from 1679 to 1772, and his services were engaged for it at a salary of £200 a year. The change in the character of his employment was beneficial to his health. He had of late been subject to fits of despondency; in one letter he wrote that he was resolved, unless those things that he had brought to some perfection rewarded him for the trouble and money he had expended on them, that he would not invent any more, if he could resist it; that when he invented the fire-engine he was spurred on by the alluring hope of placing himself above want without being obliged to have much dealing with mankind, to whom he admitted that he had always been a dupe, and he added that he must have sunk under the burden of successive disappointments but for the support of Dr. Roebuck's friendship. He was now able to write to Dr. Small and say, "The vaguing about the country and bodily fatigue have given me health and spirits beyond what I commonly enjoy at this dreary season, though they still thole amends.* Hire yourself to somebody for a ploughman; it will cure *ennui*."

His correspondence with Dr. Small enters into full particulars of the progress of his various undertakings, of the interesting subjects that from time to time absorbed his thoughts, and of the incidents of his life, and is, in fact, a valuable and full autobiography for this period of his life; all too, is written in such a straightforward, natural, unreserved style that every passage glows with the radiance of a personality that has not grown dull by custom, nor been dwarfed by conventions; and though there is in these letters a merit that deserves to live from man to man, yet to extract one half of the good from them would require not a chapter, but a volume. We see from them how anxious he was that a good bargain should be concluded with Mr. Boulton, not for his own advantage, but for the sake of that generous but unfortunate friend, who had for years been of so great service to him. "As to myself," he says, "I have never thought of receiving money for any part of my property in it, and shall perhaps be willing to hold a much smaller share in it than you would ask me. Although I am out of pocket a much greater sum upon these experiments than my portion of the property of the engine, I do not look upon that money as the price

* *i.e.*, though they would stand further improvement.

of my share, but as money spent upon my education. I thank God that I have now reason to believe that I can never, while I have health, be at any loss to pay what I owe, and to live at least in a decent manner. More I do not violently desire." And again, "It is a matter of great vexation to me that the Doctor should be out so great a sum on this affair, while he has otherwise such pressing occasion for the money." These extracts give us a considerable insight into his character. When he took up engineering, we find from the same series of letters that he found the work profitable, that his time, though still liable to the interruptions of headache and other bad health, was largely given to consultations, of which he had more than he was able to answer, and people paid him pretty well; so that he wanted little but health and vigour to make money as fast as was fit.

One paragraph more, which illustrates still further the genuineness of his character, may be added; it refers to Dr. Small's endeavours to get for him some more work of a remunerative sort: "Remember also I have no great experience, seldom choosing to attempt things that are both great and new; I am not a man of regularity in business, and have bad health. Take care not to give any body a better opinion of me than I deserve; it will hurt me in the end."

In addition to the construction of the Monkland Canal, Watt made a survey for a canal from Perth to Forfar, on behalf of the trustees for the annexed estates. He made plans and estimates for a five-arch bridge over the Clyde at Hamilton, for which he received the munificent payment of seven guineas; he surveyed the river at Glasgow with a view to its improvement for navigation; he reported on the best means for improving the harbour of Ayr, and made surveys for many canals in various parts of Scotland; among these it is worth recording that he was the first engineer to make a survey for a navigable canal from Fort William to Inverness, though it was nearly twenty years later before the undertaking was entered upon, when Telford succeeded to the work, and constructed the Caledonian Canal, as it is called.

From the midst of this work Watt was suddenly recalled to Glasgow, by news of the dangerous illness of his wife; but he reached home too late to see her alive. He had found in her a true wife and a help meet for him, and his bereavement came upon him as an unspeakable trial.

Sick at heart at this great loss, well-nigh overwhelmed by a consequent return of his besetting melancholy and depression of spirits, Watt regarded fondly the prospect of returning to the absorbing interest of his steam-engine, instead of remaining a slave to the drudgery of land-surveying. Dr. Roebuck had by this time become insolvent, and, although he was in consequence unable to fulfil the terms of his agreement, Watt, with a generosity which we should have expected from him—for the history of human conduct affords many like instances, to the credit of human nature —did not insist upon everything that was "in the bond," but discharged him from further obligation, and allowed him to retain the stipulated two-thirds of the patent. He now disposed of this to Mr. Boulton in return for a release from a debt of £630, and a promise of the first £1000 of profit that might accrue after the commencement of the proposed partnership of Boulton and Watt. This was a liberal price to pay at that time, for the engine had not yet developed into an assured success, and we are told that none of Dr. Roebuck's creditors valued his share in it at a farthing. On account of these arrangements, the apparatus set up at Kinneil House had been removed to Soho even before the survey for the Caledonian Canal was made. It was in the summer of 1774 that Watt himself went to live in Birmingham, and proceeded to occupy himself with vain attempts to devise a satisfactory rotary engine, which seemed to him to be better than the old reciprocating engine if it could be contrived, and with more or less successful efforts to improve still further on the original form. He had now reached a happiness which he could fully appreciate, the happiness of devoting his energy to his favourite invention, unembarrassed by poverty, and surrounded by the society of generous, sympathizing, and helpful friends. Amongst these were to be reckoned Josiah Wedgwood, Erasmus Darwin, and Josiah

Priestley, besides Matthew Boulton, and his friend Dr. Small.

Mr. Boulton soon procured a truer cylinder than the Carron Works had been able to provide, a new boring process having been recently introduced by Mr. John Wilkinson, an iron-founder at Bersham, near Chester. The methods previously employed were sufficiently accurate for the ruder forms of steam-engine already in use; but this of Watt's required greater precision in construction, and promised so well as to encourage the most thorough workmanship and the most rapid development of subsidiary mechanical processes.

It was still, however, evident that the new steam-engine was not the growth of a day, that it could not yet be advantageously offered for sale to the public, and that there might still be some years' work before it was completed. Meantime six out of the fourteen years during which it was secured by patent had elapsed, and it might be doubted whether the sale could begin to be profitable to the inventor before the end of the period, when it would become public property. Two courses were open; the first was to surrender the patent, and try to obtain a new one from that date; the other was to apply for an Act of Parliament to extend the time of the first patent. The second course was followed, and, notwithstanding the formidable opposition of Edmund Burke, the extension of the patent was granted for twenty-five years from the date of the passing of the Act, May, 1775. Upon this the terms of the partnership between Boulton and Watt were drawn up. Mr. Boulton bore the expenses of obtaining the Act of Parliament, and made himself liable for the expenses of future experiments and for the capital necessary to carry on the manufacture (at a reasonable interest); two-thirds of the profits, after deduction of interest and trade expenses, were assigned to him, and one-third to Watt. A great public interest in the invention had been naturally created by this time; and a general demand for the new engine seemed immediately probable.

It was under this favourable aspect of affairs that Watt brought to Birmingham his second wife, Anne, daughter of a Mr. Macgregor, of Glasgow.

Before giving himself up to the manufacture of Power, that commodity which his partner, Mr. Boulton, truly said all the world desired to possess, Watt had to resist a tempting offer of imperial employment in Russia at a salary of £1000 a year; but apart from the ardour of his devotion to his own steam-engine, there were doubts as to the reliability of the favour of princes, especially those of Russia, that facilitated his decision to remain in England. The fame of the engines, which were now coming into use in various parts of the country, travelled over to France, and in 1778, the King, Louis XVI., granted to Messrs. Boulton and Watt an exclusive privilege to make and sell their engines in France. Before the royal decree could have the force of a patent it was necessary that the superiority of the engines should first be established by trial in France. M. Perrier, who had undertaken to pump water from the Seine for the supply of Paris, was commissioned to conduct the trial, and showed his copy of Watt's engine to the greatest possible disadvantage, so that it could not but be regarded as a failure, comparing unfavourably with a *variation on it*, which he announced as the fruit of his own invention. Watt wrote to Boulton, "If we mean to keep this our kingdom of France in subjection it will be necessary that one of ourselves go over there soon." But indeed it was hard enough to maintain their rightful sovereignty in England. Almost the only use to which steam-engines were put a hundred years since was to work pumps for the purpose of draining mines or providing a water-supply for large towns; the reciprocatory motion of the piston made them immediately serviceable for such employment as this, and the first great campaign of the new invention was directed towards obtaining a foothold amongst the numerous mines of Cornwall. Watt himself was very constantly there carrying on negotiations and altering engines, and contending against the "over-reaching" propensity which struck him as characteristic of the generality of Cornish miners, and which forced him to say in one letter, "Peace of mind and delivery from Cornwall is my prayer." By the year 1783 victory had so inclined in his favour that he was able to write, "We have altered all the engines in

Cornwall but one, and many in other parts of England; but do not acquire riches as fast as might be imagined. The expenses of carrying on our business are necessarily very great, and have hitherto consumed almost all our profits; but we hope to do better by continuing our attention and exertions, and by multiplying the number of our works." Just at that time many, if not most, of the chief Cornish mines were in such difficulties that they would have had to be abandoned had not a more efficient and economical method of draining them been fortunately at hand in James Watt's invention, by the adoption of which their expenses were materially diminished, and their working continued with profit. It is an old adage that Wealth is Power; to prove conversely that Power is Wealth was found, in the experience of Boulton and Watt, a long and arduous process; but the proposition was established at last.

In the midst of these abundant labours Watt obtained patents for various further improvements in the steam-engine. In October, 1781, he patented certain new methods for transforming the reciprocating motion of the piston into a continuous circular motion, an invention that was needed before his steam-engine could be used to set carriages in motion. Some years before this he had employed cranks for the purpose, but in the meantime an engineer named Wasborough had stolen the contrivance from him "by the most infamous means," and had surreptitiously obtained a patent for it. "If the king," Watt wrote, "should think Matt Wasborough a better engineer than me, I should scorn to undeceive him; I should leave that to Matthew. The conviction would be stronger as the evidence would be undeniable." Watt was clearly right in regarding as the true inventor of the crank rotative motion the unknown genius who first contrived the common foot-lathe; its application to the steam-engine, he said, was merely taking a knife to cut cheese which had been made to cut bread. The chief of his present devices to secure the same end, and the one he employed until the expiration of the crank patent, was that of the sun and planet wheels, but it lacked the simplicity of the crank, and was merely a temporary expedient. Other important patents were granted in 1782, namely—

1. The use of steam on the expansive principle. It was one result of his many ingenious and careful experiments that if the supply of steam were cut off before the piston had finished its stroke, the expansive force of the steam already in the cylinder would exert pressure enough to complete the stroke; hence a smaller supply of steam, when so regulated, was required to do a certain amount of work. The portion indicated by Watt as being most convenient for admission was one-fourth of the contents of the steam vessel, producing an effect equal to more than one-half of that which would have been produced had steam been admitted

freely to the cylinder during the whole stroke of the piston.

2. The double-acting engine, in which steam is admitted to press the piston both upwards and downwards, the piston being also aided in its motion by a vacuum produced by condensation on the side towards which the steam is pressing it.

3. The double engine, consisting of two engines, primary and secondary, of which the steam vessels and condensers communicate by pipes and valves, so that they can be worked either independently or in concert; so, for instance, that the steam which has been employed to press on the piston of the first may act expansively on that of the second.

Watt was the first to invent and apply to steam-engines an instrument called an *indicator* for observing the changes of pressure of the steam or vapour in the cylinder of an engine, for which purpose a barometer was quite unsuited on account of the vibrations of the mercury due to the rapid fluctuations of the pressure; a pencil was subsequently attached to the index, and this traced a line on a sheet of paper which moved backwards and forwards in unison with the up and down stroke of the piston; the closed curve thus drawn is a diagram of work done, and plays a most important part in comparing the efficiency of different engines. In Watt's description of the invention of expansive working is a drawing which furnishes the first published example of such a diagram as applied to a steam-engine; he saw that it was necessary to measure all the measurable quantities, which had to be considered in the working of his engines, in order to obtain an accurate knowledge of things as they were and of their possible improvements. It was this that made him foremost amongst philosophers, as he was foremost amongst practical inventors. At the meeting of the British Association at Southampton in 1882, Dr. C. W. Siemens, the president of the Association, in his inaugural address referred to the necessity of accurate measurements and of a correct determination of units of measurement. He proposed a certain unit for the measurement of power, and suggested that it should be called a Watt, "in honour of that master mind in Science, James Watt. He it was who first had a clear physical conception of power, and gave a rational method of measuring it."

In 1784 another important patent was obtained; the specification included a steam-hammer for forging iron and steel; also the ingenious and simple contrivance for parallel motion, or for making the piston-rod move perpendicularly up and down without chains or perpendicular guides or untowardly friction, arch heads or other pieces of clumsiness. In a letter written many years later Watt wrote, "Though I am not over-anxious for fame, yet I am more proud of the parallel motion than of any other mechanical invention I have ever made."

Watt had already been accustomed to regulate the supply of steam to the cylinder by what is not inaptly called a throttle valve, which was turned by the hand so as partially to close the steam-pipe to any desired extent; if the engine is working too fast, less steam must be admitted, if too slowly, more steam is required. He now contrived an effectual automatic method of controlling the supply, for he saw that only by some such means could perfect uniformity of speed be secured; if the engine itself could be made to regulate the supply according to its own needs, it would act more promptly and efficiently than the most attentive engine-man; thus Watt's object was to make every engine in this respect its own engine-man. A vertical rod was made to revolve by a band passing round it and round the axis of the flywheel; from joints at a point on the rod two arms were suspended, carrying heavy metal balls at their lower ends; the greater the speed of the flywheel of the engine, the more rapidly did the vertical rod revolve, and the further did the balls fly out from it in their revolution; the arms to which these were attached, being in consequence raised, moved a system of levers which partially closed the throttle valve if the speed were greater than was required, and in so doing cut off part of the inrush of steam and diminished the speed of the engine. This was the application of the governor to regulate the speed of the engine, and it is employed still in exactly the form in which Watt left it. So successful was it that, when steam began to be introduced into cotton mills, the steam-engine of one Manchester mill itself served the purpose of a clock, and indicated the time by the familiar clock-face and hands with as great accuracy as the pendulum clock.

By the terms of the agreement with the Cornish miners the firm of Boulton and Watt were to receive at first one-third of the savings of fuel made by each engine, to be paid annually or half-yearly, with an option of redemption at ten years' purchase; but the Cornish miners were a shrewd race, and not over-scrupulous in keeping an account against themselves; after much wrangling with them Watt met the difficulty *more suo* by making every engine keep its own accounts by means of a tell-tale counter, thus removing the temptation to deception. In 1784 Boulton estimated that the annual dues from their mining-engines would amount to about £12,000, if duly paid.

Besides the above inventions, may be mentioned the steam-gauge, and a successful contrivance for making engines consume their own smoke, which testified to the marvellous inventive faculty of this greatest of mechanicians, and to his power and habit of searching out for possibilities of further improvements. In fact, from 1775 to 1785, Watt would seem from this brief record, in which the half is not told, to have spent his time in nothing else but either to invent or adapt some new thing; and yet we know that a heavy share of the extensive business transactions of the firm fell to him, and his son subsequently wrote that during the greater part of the time he well remembered seeing him suffer under most acute headaches, sitting by the fireside for hours together, with his head leaning on his elbow, and scarcely able to give utterance to his thoughts. It was unquestionably the busiest as well as the most anxious period of his life, and its many things attempted resulted in many things done, of which we now reap the advantage.

We have seen that Watt had devoted some time to chemical studies. In the year 1783 he added to his other scientific triumphs the discovery of the composition of water, which had hitherto been regarded as an element. There was a long controversy on the question of priority, but there seems no reason to differ from the opinion expressed by Liebig, that the idea was first published by Watt, though the fact was first established by Cavendish.

Another valuable suggestion, upon the advantages of which Watt warmly insisted, was that there should be a uniform system of weights and measures for scientific purposes, to be used by the philosophers of all countries; this desirable result is now being gradually attained, under *measures* being included the units of all measurable quantities; and as we have said, it has been proposed that one of these units should be called a Watt in recognition of his services to science, and in token of the honour in which he is held by scientific men everywhere.

It was not before the end of the year 1787 that the firm was able to cancel all the vast debts that had accumulated in its early days, when all was expenditure and nothing brought profit. By the end of that year, however, all the debts were discharged, and some £6000 were transferred to Watt's private account. Although Boulton was at this time in considerable difficulties, yet at the request of his partner, he gave up the extra share of profits to which he was entitled by the terms of partnership, and the profits were divided equally between them. So eager was Boulton to encourage enterprise that he frequently did so at considerable cost to himself, and without in every case investigating the soundness of the speculation. If a mining adventure was started in Cornwall for which a new engine was wanted, Boulton, it is said, would write—"If you want a stop-gap, put me down as an adventurer." He once purchased large quantities of copper from a mining company, in the hope that he might use or sell it, but it lay a long time on his hands a useless and unsaleable possession. The time came, in fact, when the position of the two partners was reversed, and Boulton in his need would have been glad to borrow from Watt, but Watt had prudently and promptly invested his profits, and could give no help. It was a trying time to pull through, for in the midst of the commercial crisis it was impossible to borrow the money he wanted; and he had his hour of despondency that might compare with those which Watt had lived through in his younger days. He had long been interested in the question of reforming the coinage, and he now determined to apply the steam-engine to this purpose. He obtained in process of time large contracts from foreign Governments, and finally from that of England, and was subsequently entrusted with the erection of the Mint on Tower Hill, according to his own plans; and he supplied mints for the Russian, Spanish, and Danish Governments, for Mexico, Calcutta, and Bombay. By his labours he dealt a death-blow to the coining of counterfeit money, which up to that time had been so prevalent because so easy, and for which Birmingham possessed an unenviable notoriety. By this means Boulton well earned the fame of his later years, and his fortunes emerged from the momentary cloud that overshadowed them; momentary it would have been even apart from this, for the engine now brought to the firm a constant stream of golden coin. In addition to its work in the mines, it was gradually employed in cotton and corn mills, in iron works for rolling and hammering iron, for coining money, for stamping medals, for working machinery of all sorts, and generally for doing a great variety of work which had previously required the labour of man or beast, or the application of wind or water power. In 1787 Watt had an interview with the king at Windsor, who asked him what sort of engines they were making; he replied, "for almost everything, but at present principally for brewers, distillers, cotton-spinners, iron-men, etc," that they were paid by horses' power, £5 a year, that they made none under four horses' power, and that in large engines this premium afforded sufficient profit.

Before the twenty-five years of the extended patent had expired, the firm of Boulton and Watt had to bear the trouble and expense of two law-suits which they found it necessary to institute against two of the chief infringers of their patents. The most reckless offenders were their old enemies, the miners of Cornwall, who at length refused to pay any more dues whatsoever on the engines they were using, in the fond trust that it might not be thought worth while to enforce the terms of the agreement for the remaining few years of patent right. The proceedings were not terminated until those years had almost run, it was not till 1799 that judgment was given in favour of the firm. These lawsuits probably cost them £10,000, but enabled them to recover dues that were in arrears amounting to three times this sum.

When the patent expired in the year 1800, the partnership between Boulton and Watt also terminated; but the business, which, at much cost and with much risk and with only an earnest of future profits, they had by this time firmly established, was carried on by their sons; and the reputation of the firm for the excellence of its workmanship secured for them the great bulk of the rapidly extending business, notwithstanding the competition which they now had to meet; so that they had more work on hand than in the days of the patent itself, and the firm at length reaped the fruit of the many years' hard struggle of its veteran founders.

Watt was now sixty-four years of age and was heartily glad to withdraw from the cares of business; there were nobler thoughts and nobler cares that attracted him to the pursuit of new inventions, some one or more of these he always had on hand for his amusement to the very end of his life. "Without a hobby horse," he said, "what is life?" and he was never at a loss to find some hobby, new or old, to engage his attention. The share of wealth that he had brought out of the Soho business he delighted to invest in land, and, as occasion offered, added acre on acre to his estate at Heathfield, near Birmingham. He also undertook expeditions to various parts of the country in search of desirable estates, but he generally found out something undesirable in the roads or neighbourhood; he, however, found a place to his liking at Doldowlod, on the banks of the Wye, in Radnorshire, and purchased considerable property there, including a farm where he sometimes spent the summer. These years were indeed the quiet harvest of his life, and would have been in all respects the brightest, but that they of necessity took a sober colouring from an eye that had kept watch o'er man's mortality. The friends of his first struggles, and those that in his maturer manhood he had learnt to know and love after his removal to Birmingham, passed away one by one, and in dear words of human speech they could communicate no more. Josiah Wedgwood died in 1795; Dr. Black in 1799; Dr. Darwin in 1802; Priestley died a year or two later in America, whither he had fled for refuge after the Birmingham riots of 1791, in which he paid the penalty of his sympathy with the principles which expressed themselves in the outburst of the French Revolution, by the loss of invaluable manuscripts in which were treasured the result of long years of scientific research; Dr. Robison died in 1805; and Mr. Boulton in 1809. In addition to the loss of these friends, all illustrious men, Watt had to bear painful bereavement within the family circle; his two children by his second wife, a son of the highest promise and a daughter whom he dearly loved, fell victims to consumption. His elder son, James, had succeeded to his own place in the business at Soho.

Amongst the associates of Watt there was one remarkable figure that should not be left unnoticed. This was William Murdock, who was engaged as a servant of the firm in its early days, became its mainstay in its difficult negotiations in Cornwall, and, besides, proved himself to be an inventor of a very high order. When Watt first went to Soho he was followed by the importunity of many a "brither Scot," who trusted to the instinctive clannishness of their race, and expected to have work for the asking. Amongst others came Murdock, and had an interview with Boulton, who did not at first give him much hope of employment, but his attention was caught by a most peculiar hat which the young Scotchman was nervously twirling in his hands.

"That seems to be a curious sort of hat," said Boulton. "Why, what is it made of?"

"Timmer, sir," said Murdock.

"Timmer! Do you mean to say that it is made of wood?"

"Yes, sir."

"Pray, *how* was it made?"

"I turned it mysel', sir, in a bit lathey of my own making."

Boulton at once determined to give him a chance, and he rose rapidly to a position of the highest trust in the business. In Cornwall his aid was invaluable, and he was popular, too, among the miners there, notwithstanding his mission; for his thorough manliness, and his ability in dealing with men, and his tact in overcoming opposition were characteristics that appealed directly to the better instincts of the rough Cornish adventurers. Besides being a man of business able to cope with the determined opposition which he encountered, he was also equal to suggesting many improvements of the steam-engine which were adopted by the firm; and as an inventor he was as assiduous and bold almost as his master himself. The first acting model of a steam locomotive was made by him during his residence in Cornwall in the year

1784, and in the evenings which brought him leisure he ran it on the paths leading to the vicarage at Redruth, at first to the great consternation of the vicar, whose latent superstition was much aghast at the sight. But Murdock's greatest claim to distinction is that we are indebted to him for the first idea of applying and for the first actual application of gas to economical purposes. He lit up his house at Redruth with gas in 1792, and had a gas hand-lantern made to light him over the Cornish moors at night. In 1798 gas was regularly employed to light some of the offices at Soho, and the whole of the front of the manufactory was illuminated with the new light on the occasion of the rejoicings at the conclusion of the Peace of Amiens in 1802. By this time people were beginning to think that there might be "a future" before gas; that, although it could never be used with advantage in private houses, yet it might be found serviceable in factories, theatres, and large halls. Several large firms made the attempt with success, amongst them Lee and Kennedy, of Manchester, the friends of Crompton. The subject of the new illuminating power found its way into Parliament, and Murdock had to give evidence before a committee. "Do you mean to tell us," asked one member, "that it will be possible to have a light *without a wick?*" "Yes, I do, indeed," replied Murdock. "Ah, my friend," said the wise legislator, with a knowing shake of his head, "now you are trying to prove too much."

At length gas made such progress that the House of Commons was lighted with it. The architect, however, insisted upon the pipes being fixed several inches from the wall for fear of fire, and honourable members might have been seen cautiously touching these pipes with their gloved hands, and lost in astonishment that they were not hot to the touch as though this strange gas which gave light without a wick were brought through the pipes in the condition of ready-made flame.

Unfortunately Murdock did not take out any patent for this most valuable invention; he had intended to do so, but the business of the firm was at the time so exacting that he deferred taking this step until it was too late. He survived Watt some twenty years.

During the remnant of his days, passed in peace and comfort at Heathfield, near Birmingham, James Watt never ceased to occupy himself in the one way for which nature and habit alike qualified him. His favourite room in his house was "The Garret," which was fitted up with mechanical and chemical apparatus, and supplied with all the requisites of experimental philosophy which he needed. Some of his latest endeavours may yet be a light to guide some young inventor to an idea of wide public utility. He spent some time at an arithmetical machine, but his interest was at last chiefly centred in a machine for copying sculpture, which he brought to a practical success. He humorously presented many specimens of his work to his friends as the "first attempts of a young artist just entering on his eighty-second year." This machine he was always trying to improve. The thoughtful philosophy of ancient Greece had laid it down that in every one of us there are two ruling and directing principles, whose guidance we follow wherever they may lead, the one being an innate desire of pleasure, the other an acquired judgment which aspires after excellence. In Watt the aspiration after excellence seemed as natural as any desire for happiness. He regarded his sculpture machine as at least having the good effect of making him avoid many hours of *ennui* by employing his hands when he could not employ his head, and of giving him some exercise when he could not go out. Like his friend Boulton, he preferred to come to his end by rubbing rather than by rusting; thus in these congenial occupations, in the enjoyment of the friendship of the most thoughtful men of his time, and of honour from all, he who had served so well not only his own, but all succeeding generations, and had given an impulse to English prosperity for which England cannot be too grateful, lived out his day in peace, and in the fulness of years "fell on sleep" on the 19th of August, 1819. He was buried in Handsworth church, where the remains of his partner, Matthew Boulton, also lie interred.

One of the treasures of Westminster Abbey is a fine monument by Chantrey, who was one of Watt's numerous friends ; on it is this inscription due to Lord Brougham :—

"Not to perpetuate a name
Which must endure while the peaceful arts flourish,
But to show
That mankind have learned to honour those
Who best deserve their gratitude,
THE KING,
His Ministers, and many of the Nobles
And Commoners of the Realm,
Raised this monument to
JAMES WATT,
Who, directing the force of an original genius
Early exercised in philosophic research
To the improvement of
THE STEAM-ENGINE,
Enlarged the resources of his country,
Increased the power of man,
And rose to an eminent place
Among the most illustrious followers of Science,
And the real benefactors of the World.
Born at Greenock, MDCCXXXVI,
Died at Heathfield, in Staffordshire, MDCCCXIX."

CHAPTER III.

GEORGE STEPHENSON.

THE man to whose energy we must with gratitude ascribe the necessary and sufficient impulse for the successful initiation of our railway system was born in the humblest of circumstances, endowed with little of outward things promising to make his life of national importance, but blessed with a sturdy spirit in a strong body, and distinguished amongst his fellows, even early in life, by indulging in definite *ambitions*, albeit of a lowly and limited character. In fact, it was a peculiarity of his ambitions, and is probably one of the secrets of his success, that he concentrated his hopes upon, and directed his endeavours towards, an advance of one step at a time in his position, and when this was secured, as alone it could be satisfactorily secured, by thoroughly fitting himself for the next step in his desired promotion, then he was not content to rest at that stage, but with unceasing but unhurrying activity he set about equipping himself for a further advance. The successes that crowned his efforts and made his name a name of honour everywhere were not dreamed of at the outset of his career; for him to have indulged in such dreams then would have been vain indeed, but it was practical and wise of him to aim at being the best and most intelligent workman at his own branch of pit-work, and to begin by progressing from the lower to the higher levels of this humble employment. This is the sort of ambition that makes useful men, and that has given the world great benefactors.

George Stephenson, the second son of Robert Stephenson, fireman of an old colliery pumping engine, was born at Wylam, on the north bank of the Tyne, some eight miles above Newcastle, on the 9th of June, 1781. The house in which he was born is a small cottage with four rooms, two above and two below, each room being the home of a labourer's family; the walls, we are told, are now as they were then, unplastered, the floor of clay, and the bare rafters unconcealed and unadorned stretched overhead. Robert Stephenson earned at Wylam but twelve shillings a week, on which he had to support his family of six children. We therefore are not surprised to learn that none of the children could be sent to school; it was hard to give them bread to eat, it was impossible to provide them with such ordinary means of self-improvement as are now so universally attainable, and so generally considered essential to success in life. Out and about in the grimy village, playing with other children of his class, utilized when possible for errands or messages, the object, we may be sure, of no demonstrative love or excessive care, thus the boy George must have passed his days; but that he had some half-formed hopes beyond his daily pastimes is evident from the zest with which he set about his work as one of the world's workmen when his time was fully come. His father was an honest worker, and the important head to which the family which was crowded into the bare room at Wylam looked for their daily bread, in his honesty and industry a pattern to his children. The sturdy George had as a boy enough of the man in him to make him desire the independence and importance that the receipt of wages would give him, and throughout the vicissitudes of humble employment that came to his hands even in his childhood, he cherished the ambition of following in his father's footsteps, and longed to be "taken on at the pit." His first ambitions were soon satisfied, and by the time he was fourteen years of age he had been promoted to be assistant fireman at a shilling a day. When the family migrated in search of work to Jolly's Close, near to the village of Newburn, George was appointed fireman at the Mid Hill Winnin, and he set to work to acquire a thorough knowledge of the construction and action of the engine entrusted to his charge, so that he might be competent for the higher and better paid appointment of engine-man. His dominant principle of limited, concentrated, and eminently practical ambition kept him steadily devoted to this one object, and saved him from all excesses to which his fellow workmen might be tempted; amongst them his real merits were never guessed at, but he must have been in high esteem among them on account of his physical strength and his pre-eminence in such pastimes as hammer-throwing and lifting heavy weights, in which they indulged their leisure. It is said that on coming out of the foreman's office on the first occasion of his receiving twelve shillings a week, he announced the fact to his fellow workmen, and added triumphantly, "I am now a made man for life!" But he soon found a higher goal to seek.

When he was appointed engine-man at the age of seventeen, with his father holding the inferior appointment of fireman with him, he had more responsibility and more opportunity of studying the engine, and of this he availed himself with a steady perseverance, pulling the engine to pieces and cleaning it part by part in his leisure hours, making of it a hobby that in turn made the engine-man's daily toil interesting to himself and most profitable for the world. As a rule, when anything went wrong with a pit engine, and the engine-man was unable to remedy it, the chief engineer of the colliery was called in; but George Stephenson soon knew more about his engine than any of the engineers of the neighbourhood, and not only was he thoroughly independent of their assistance, but he was frequently consulted in cases where they had failed. He had heard of the engines of Boulton and Watt, far superior to those he had himself seen and worked; he greatly desired to know something about these engines, and for that, and for the sake of other knowledge then hid from him in books, he decided to put himself to school in order to learn to read, and thus to cancel one of the deficiencies of his education. Love of knowledge was a more powerful motive with him than shame, and so, grown man as he was, he went to school to learn the three R's; and by his engine-fire at night he did a great deal of his school-work. He determined to remove every obstacle that stood in the way of his progress, and saw that if it was not too late in life for him to think of bettering his condition, neither was it too late for him to begin at the humblest stages of self-improvement. At any rate he was eager to know as much as he could about engines and their most recent improvements, and he therefore willingly became the pupil of a poor night-school master at the neighbouring village of Walbottle, and soon made astonishing progress, and with a natural instinct to discern what knowledge can perform, was diligent to learn. A still higher appointment than that of engine-man was that of brakesman; it involved the responsible superintendence of the working of the engine and of the machinery by which the coal was drawn up from the pit. It was with difficulty that George Stephenson was able to get any practice at this work owing to the jealous opposition of other workmen; but these obstacles, too, he at last overcame, and in 1801 he was appointed brakesman at the Dolly Pit, Black Callerton. Here he lodged with a small farmer, and here he married Fanny Henderson, who was a servant in the house where he lodged; she was modest, kind, sweet-tempered, gifted with common sense, and she made him a good wife. It was at Black Callerton that George had a fight with a big bully of the name of Nelson. To the astonishment of the villagers George did not shrink from the fight. "Ay; never fear for me; I'll fight him," said he; and to the astonishment as much as to the delight of the villagers the bully was thoroughly thrashed. This was the end of George's being bullied, and the last of his fighting.

George Stephenson's first invention dates from about this time, when he was twenty-one years old. He had continued taking as much interest as ever in his engine; he still spent his Saturday holiday in taking the engine to pieces and cleaning each part, so that by this constant practice he kept and indeed increased his acquaintance with it. He was now able to occupy his leisure evenings by reading and writing, and he made it his steady aim to learn in that way all that he could about the mechanical principles that governed the action of his engine. To all this he must have been in the first place impelled by the necessity of satisfying his own craving after knowledge, but at the same time this virtue was preparing him for a most useful future, and working out for him a reward of abundant success and fame beyond his most sanguine hopes. His first invention was an engine-brake; but it was merely a first experiment, and did not prove practically useful. Clock-cleaning was one of his profitable occupations, for which he became fitted by the necessity of taking to pieces and cleaning his own clock when it had been damaged by a disastrous fire in his little cottage.

It was in October, 1803, that George Stephenson's only son Robert was born at Willington Quay; about a year later his wife died. Hitherto Stephenson had lived in various colliery villages in the neighbourhood of Newcastle, but he now accepted an invitation to superintend one of Boulton and Watt's engines at some spinning works near Montrose, involving a trudge of some 250 miles there, and the same back again at the end of a year with £28 in his pocket. This he devoted partly to the support of his aged parents, and partly to buy himself off from military service, for which he had been drawn. Between this time and the year 1808 things went very badly with George Stephenson; he would, indeed, have joined his sister and brother-in-law and emigrated to America, but his funds were too low to allow his doing so. He was thirty years of age when he first received any money as a recognition of superior ability and skill, thirty years before he was distinguished amongst his fellows by anything more than his soberness and reliability and steady work. And yet the man who at thirty was proud of a gift of £10 for having set to rights, at the Killingworth High Pit, a faulty pumping-engine that had baffled all the technical skill of the neighbourhood, inasmuch as it was the first recognition of his extraordinary merit, astonished the world in less than twenty years' time by making one of his own engines run at a rate of thirty-six miles an hour, and by constructing the Liverpool and Manchester Railway, which involved engineering tasks declared by the most prominent engineers of the day to be impossible. His success in altering the pumping-engine at the Killingworth High Pit resulted in his being appointed enginewright of the colliery, in 1812, at a salary of £100 a year.

We must not omit to mention here another duty that fell to him, and one which he engaged in with all the practical earnestness of his nature; this was the education of his son Robert, whom he was determined to endow with all those advantages, the want of which had made science to himself indeed "an obstinate hill to climb." With a view to this he had by the year 1815 saved £100, and was able to send Robert to school in Newcastle; at the same time he was continuing his own studies with his habitual steadiness, and the example he set to his son by the quiet and ever-industrious way in which he spent his evenings must have done more for the boy's education than any direct teaching could do, by setting before him an example of a most impressive though most unostentatious kind.

He made the advantages which his son was enjoying subservient as far as possible to the extension of his own knowledge. Robert regularly carried home from the library of the Literary and Philosophical Institute scientific books for perusal with his father; others he read at the Institute, and in the evenings explained to his father what they contained. Thus in reading, drawing, and modelling the evenings were occupied, and the two Stephensons, father and son, were achieving such an educational success in their own persons, developing and training their mental powers to such advantage, as may well put to shame almost every other educational effort the world has ever seen.

We may be sure that whenever and wherever George Stephenson heard anything about improvements in the steam-engine, he gave all his attention to learn in what the improvement consisted; and when rumours came of new applications of the engine, to these he must have listened with a deep and intelligent interest. By thoroughly understanding the machine as it was then used, and by acquiring a clear insight into the objects of the various proposals for extending its usefulness, he was exactly in a position to further any improvement in it that might come under his notice; a steady life, high aims, and the aptness called talent did this for him, and would have made his life honourable and serviceable even without that commanding genius which soon developed in him, and which, in the face of opposing difficulties that most men might with good excuse regard as insuperable, enabled him completely to revolutionize the locomotion of the world. Since his boyhood the sight of a tramway had been familiar to him ; one of the earliest of these roads in England passed in front of the cottage in which he was born, and the trams were clumsily hauled along its wooden rails by toiling horses. This railroad was at least so far superior to the ordinary village roads as to make it worth the expense of maintenance in a workable condition. In 1808, Mr. Blackett, to whom it belonged, had it laid with cast iron ; this was so much better that it could be worked with much greater profit. The successful introduction of steam locomotives on colliery tramways is due to Mr. Blenkinsop, of Leeds, and dates from the year 1811 ; one of the driving wheels of his engine was toothed, and worked into a rack on the rail, for the notion was then universally held that a smooth wheel would not bite on a smooth rail, but would simply revolve without rolling. Various expedients were devised with a view to meet this same supposed difficulty—such as having a chain stretched the whole length of the road and coiled once round a drum on the axle of the driving wheels ; and, again, setting up a machine with legs to be moved alternately like those of a horse. Mr. Blackett, of Wylam, attempted to adopt the tooth-wheel and rack-work on his railroad in 1812, but his first engine burst all to pieces as soon as it was tried. The next one had an inconvenient habit of leaving the rails. We are told that the driver was one day asked how he got on. "Get on?" he replied; "we don't get on, we only get off." The problem of steam locomotion was thus fairly before the world, although it was embarrassed by imaginary difficulties. To Mr. Hedley, the viewer of Mr. Blackett's colliery, must be ascribed the credit of showing that all these expedients to prevent slipping were as unnecessary as they were unsatisfactory; he proved by carefully conducted experiments that the weight of the engine would of itself secure that the wheels should bite, and that the engine could therefore, without any such ingenious contrivances, draw a train of waggons after it on a smooth road. As a matter of fact the devices that had been designed to facilitate motion only impeded it; no rails and no wheels are absolutely smooth, and the small roughnesses of the smoothest, together with the compression due to contact, are quite enough to call into existence the friction needed for locomotion. Until, however, Hedley showed this to be the case, it had been one of the chief objects of locomotive engineers to provide what they conceived to be the necessary additional friction.

Mr. Hedley's engine, the "Puffing Billy," is to be seen in the museum of the Patent office, and on it is the following inscription: "This is the oldest locomotive engine in existence, and the first which ran with a smooth wheel on a smooth rail. It was constructed, under Mr. Hedley's patent (A.D. 1813, No. 3666), for C. Blackett, Esq., the proprietor of the Wylam Colliery, near Newcastle-upon-Tyne. After many trials and alterations it commenced regular working in 1813, and was kept in constant use until June 6, 1872, when it was purchased for the Patent Museum." This improvement was adopted at Wylam, and at the same time another step in advance was taken by returning the flue through the boiler, so that a larger surface was exposed to the heat, and therefore a greater amount of water could be converted to steam by burning the same amount of coal. This was one of the means for economizing heat, which was afterwards considerably developed, and proved to be of the utmost importance in securing the success of the locomotive.

Stephenson signalized his acceptance of the Killingworth appointment by active measures to improve the working of the colliery. A stationary engine at the bottom of the shaft, that had hitherto been employed merely for pumping purposes, he turned to further account by making it draw the coal up inclines from the deeper workings. He instituted, where practicable, inclines from the pit down to the wharves, so that the loaded trams in descending could draw back the empty ones on their return to the pit. In every way he satisfied the lessees of the colliery that they had obtained a most efficient enginewright, and one whose sound practical sense might be trusted in every improvement he proposed. He at this time went frequently to see how Mr. Blackett's engines were getting on, and from their performance he formed an opinion on their merits, and there was shaped in his mind the idea of a desideratum beyond anything that had yet been accomplished. It was after he had seen one of Blenkinsop's engines, which in September, 1813, was run on the tramway at Coxlodge, that he first attempted to make an engine himself. He probably reflected that all his skill in dealing with the stationary engine was due to his intimate practical acquaintance with it, and that if he hoped to develop the locomotive into a real success, he must first of all take it as it is, and thoroughly examine its working with a view to finding out its deficiencies. Stephenson was not deterred by the fear of making a faulty engine to begin with; he did not wait till such time as he might feel sure of having perfected the engine in his own mind; to practical men the suggestions for improvement come from the experience of defects. It has been truly said that the man who never makes a mistake never achieves anything great; the failure of early endeavours is an inevitable stage towards the success of maturer efforts. In his first engine, however, Stephenson embodied one or two improvements. By his own experiments he had independently proved what Hedley had also established, that there was, on a moderately level road, sufficient friction to prevent slipping; he therefore dispensed with the rack rail. At the same time he attempted to remedy the absence of springs by a contrivance for relieving the four supporting wheels of a great part of the weight, a course rendered important on account of the great inequalities in the tramway, owing to the badly laid rails. In other respects, too, his engine was not a mere copy of those already in existence. It was first tried on the Killingworth Railway on the 25th of July, 1814, and after a careful study of its capabilities and its faults for a few months Stephenson early in 1815 patented an engine which should combine in a remarkable degree the essential requisites of an economical locomotive,—that is to say, few parts, simplicity in their action, and great simplicity in the mode in which power is communicated to the wheels supporting the engine. He had set before himself the problem of constructing a locomotive engine which should do more work by a simpler mechanism and at a smaller cost than any that had yet been invented. Since steam was the agent to be employed, he desired to generate the steam as fast as possible; for this purpose he required to expose as large a surface of the boiler as possible to the action of the fire, and at the same time to make sure of a quick fire. The engine, being subject to the requirement of rapidity in the motion of its massive parts, had to be worked by steam at high pressure, which, after employment in the pistons, had to be discharged into the atmosphere to the no small inconvenience of neighbours, we are told. It occurred to Stephenson that this waste steam might well be utilized as a blast to stimulate combustion in the furnace, and for this purpose he conveyed it into the chimney, and allowed it to escape in a vertical direction, so that its velocity was imparted to the smoke from the engine, and the desired result was obtained. This was one desideratum for increasing the generation of steam; the other was secured by the adoption of the multitubular boiler; but this was the result of further experience and of renewed laborious investigation of the problem before him. In the engine of 1815 the following are the important improvements on all previous attempts, as summed up by Robert Stephenson: simple and direct communication between the cylinder and the wheel rolling on the rails; joint adhesion of all the wheels, attained by the use of horizontal connecting rods; and finally, the steam blast mentioned already. Robert Stephenson adds that it is, perhaps, not too much to say that this engine, as a mechanical contrivance, contained the germ of all that has since been effected. It may be regarded, in fact, as a type of the present locomotive engine. The next great improvement, the multitubular boiler, could never have been used without the help of the steam blast, by which power only the burning of coke was rendered possible.

In those days there was no class of skilled mechanic able to turn out exact and true work such as is seen in all engines now. Amongst other things it was then impossible to make springs of sufficient strength to support the heavy engines, and contrivance had to find some temporary substitute. The permanent remedy, however, consisted in training workmen to the required skill, and encouraging excellence by the prospect of permanent employment; now that this has been done, we need no longer occupy ourselves with the temporary contrivances, but can happily turn from them, with a "Nous avons changé tout cela."

The locomotive was by no means the sole subject that engrossed Stephenson's attention at this time. It was in his mind but one of many means for improving the prospects of colliery enterprise; and he strove to make every department of colliery work more efficient and more economical. He attained his object; and the locomotive engine, which was but a detail in his comprehensive plans, soon acquired an independent and world-wide importance, so that we are apt now, in the blaze of this splendid invention, to be somewhat blinded towards Stephenson's accompanying achievements. As soon as he was appointed enginewright at the Killingworth Colliery he proceeded, as we have seen, to employ steam in the mines for the sake of hauling the coals to the shaft: if steam could be used above ground for drawing the coal, why not below ground too, where the loads had often a considerable distance to traverse before they came to the bottom of the shaft? Whilst recognizing the wide applicability of steam as an agent for doing work, he saw that the mode of application must be varied to suit the various conditions of the work; and underground he employed stationary engines. He was not so absorbed in the merits of the locomotive which he had invented as to desire to use it for any and every purpose; he was always weighing its merits against its demerits with a calm critical judgment, improving it, shaping it anew, re-adapting it as occasion might suggest. The use of steam was to him the great principle; any one form of locomotive or stationary engine was but an illustration of the principle, and by no means excluded others from his consideration. He saw, too, that the efficiency of the engine was considerably impaired, owing to the very badly laid rails along which it had to run. At every joint in the rails there was most likely a good jolt; sometimes the jointings were so bad, owing to the unequal subsidence of the ground under the heavy traffic, that the rails were broken by the shock, and even the engine thrown off the line. At any rate the engine experienced great resistance in overcoming these obstructions, and Stephenson perceived that the rails themselves demanded greater attention than had yet been given to them, and that well-laid rails, which would not cause this constant jolting and straining of the engines, were essential to the success of steam locomotion. Accordingly he designed a new joint, and a new chair to support the rails at the joint, and patented the invention in conjunction with Mr. Losh, of the Walker Ironworks, Newcastle. He obtained permission from the lessees of the Killingworth Colliery to spend two days a week at the Walker Ironworks, and Mr. Losh engaged to give him a salary of £100 a year with a share in the profits of his inventions. Railroad and engine Stephenson regarded as parts of one machine, and the rail and wheel he called man and wife. He now turned from the rail to the wheels, and saw that if these were made of wrought iron instead of cast they would be lighter and stronger; and this plan he adopted in the engine of 1816. Mr. Smiles says that it is a fact worthy of notice that the identical engines constructed by Stephenson in 1816 are to this day in regular useful work upon the Killingworth Railway, conveying heavy coal-trains at the speed of between five and six miles an hour, probably as economically as any of the more perfect locomotives now in use.

To his other achievements, Stephenson added the invention of a safety-lamp. He desired to make the working of the colliery not only more efficient and more economical, but also safer. The terrible catastrophes that he had himself witnessed, and the grievous conviction that the price of coal was to be counted *in pitmen's lives*, directed his attention to the improvement of the miner's lamp. His endeavours were successful, and he was thus the first to grapple successfully with the problem of providing a safety-lamp. In this he anticipated Sir Humphry Davy, who, on account of the great loss of life in coal-mines, had been requested to see whether he could not suggest some less dangerous way of lighting the miners at their work. These two men—one of them worthily renowned throughout the length and breadth of the land for his scientific eminence, the other as yet unknown to fame, but actuated by an ardent and intelligent desire to save the companions of his everyday life from a terrible fate,—the one president of the Royal Society with the rewards of merit already won, the other a colliery enginewright with the rewards of his equal merit still future and problematical,—were both more or less successful in their common but independent endeavours. Stephenson carried on a series of strictly scientific experiments, founded on the idea that if the current of air from the flame of a lamp escaped through a tube of a given diameter, there was some velocity of escape great enough to prevent the fire-damp from getting down to the flame and exploding, and the lamp might therefore be placed in the midst of an explosive atmosphere without risk of catastrophe, if only the current suited to the size of the tube could be ensured. In accordance with these principles and with the results of his experiments, he had a lamp made, which was tried on October 21, 1815; he improved this into a second, which was tried on November 4th. It was not till November 9th that Sir Humphry Davy presented his first lamp to the public, and by the thirtieth of that month Stephenson had finished and tested his third lamp. Sir Humphry Davy's lamp is an illustration of the fact that flame will not pass through a sheet of wire gauze; he therefore surrounded his lamp by such a sheet, so that air could get to the lamp but the flame could not pass away from it. Each hole in the wire gauze is, of course, a tube of small diameter, and the principle underlying Sir Humphry Davy's lamp is therefore the same as that which Stephenson had adopted; but the tubes were so small that an indefinitely large number of them had to be used. In Stephenson's second lamp he reduced the diameters of his tubes and inserted several of them; and pursuing the investigation still further, it occurred to him that if he made holes in metal plates placed as far apart as the length of his tubes, the required object would be secured: this, which is a somewhat near approach to the Davy lamp, was the improvement embodied in the third "Geordie" lamp. It is beyond question that, though the Davy lamp was the neater contrivance of the two, Stephenson's invention was an original and very valuable contribution towards the solution of a problem of vital importance. It is sad, however, to have to record that, at the time, his merits were blindly ignored and his claims derided by certain small-minded friends of Sir Humphry Davy. They forgot that a man might be unknown to fame, not from deficiency of merit, but because his time had not yet come. It is a melancholy reflection, too, that it was the scientific class who for the most part proved such unscientific and prejudiced partisans in the unhappy contention that followed with respect to the priority and originality of the two inventions. Even as late as 1831, Dr. Paris, in his "Life of Sir

Humphry Davy," wrote—though in this short *hereafter* it is scarcely to be believed—" It will hereafter be scarcely believed that an invention so eminently scientific, and which could never have been derived but from the sterling treasury of science, should have been claimed on behalf of an enginewright of Killingworth, of the name of Stephenson—a person not even possessing a knowledge of the elements of chemistry."

On several occasions the two lamps have been tested against one another, and, though neither of them is absolutely safe when placed in a strong explosive current of fire-damp and air, the superiority for safety demonstrably belongs to the Geordie lamp.

The application of steam to ordinary road travelling was one of the possibilities which in the earlier part of this century occupied men's minds. When Stephenson first turned his attention to it, it occurred to him that a preliminary inquiry was first necessary. Before discovering *how* it could be done, he preferred investigating whether it was worth while doing. He chose first to satisfy himself as to the desirability and advantages of the application before he took any active part in furthering it. He decided against the application of steam on ordinary roads; for, apart from the question of the locomotive agent, he showed that ordinary roads were much inferior to railways in all cases where speed and economy were important. A horse can draw ten times the load on a tramway that it can on an ordinary road. Then again the gradients of ordinary roads are frequently so considerable, and even easy gradients so unnecessarily frequent, that great waste of power is occasioned by them. Stephenson decided that level roads would be one great improvement upon the highways of the time; that level roads laid with rails would completely alter the possibilities of heavy traffic; and that level railroads would be most serviceable when worked with steam locomotive engines. He devoted himself to the realization of all these three suggestions, and out of them has made a threefold cord strong enough to pull within easy reach of one another towns and countries that were far asunder. We may fancy the impression of wonder and the feeling of nascent opposition that even the first of these giant proposals must have produced in the mind of the quiet Englishman of that time; how he must have regarded as utterly unpractical, and as stamped with the seal of impossibility, a scheme for reducing to one level the highways of traffic and of travel throughout the country. If they had known as much as Stephenson himself did about the difficulty of the enterprise, they would probably have been more confirmed than ever in their opinion; and could they have foreseen the actual difficulties that had finally to be surmounted, without having a glimpse of the ability which was to overcome them, they would have regarded it as an extreme folly to countenance such an undertaking. And folly it might have been but for a man blessed with the extraordinary and almost unprecedented energy and perseverance of George Stephenson, and perhaps even for him, too, but for his unswerving belief that he was on the right track to a great success, and that the issue would be of vast benefit to the country. It was no flash of enthusiasm that carried him through all the obstructions of nature and opposition of men; it was a sound judgment, a far-sighted and true discernment of what he could accomplish if only he stuck to his self-imposed task, and of what the result would be when he had finished it. His conditions were founded upon his perception that every argument was in favour of a level railway as against the rough and hilly course of a common road. His son, in a communication to Mr. Smiles, says, "He never ceased to urge upon the patrons of road steam-carriages that if by any amount of ingenuity an engine could be constructed which could by possibility traverse a turnpike-road at a speed at least equal to that obtainable by horse-power, and at a less cost, such an engine, if applied to the more perfect surface of a railway, would have its efficiency enormously enhanced. For instance, he calculated that if an engine had been constructed, and had been found to travel uniformly between London and Birmingham at an average speed of ten miles an hour, conveying, say, twenty or thirty passengers at a cost of one shilling per mile, it was clear that the same engine, if applied to a railway, instead of conveying twenty or thirty people, would have conveyed two hundred or three hundred people, and instead of a speed of ten or twelve miles an hour, a speed of at least thirty to forty miles would have been obtained."

In the year 1819 the Hetton Colliery Company decided to have a locomotive railroad from their mine to their wharves near Sunderland, a distance of eight miles. They invited George Stephenson to be their engineer, and by an arrangement with his Killingworth employers he was able to accept the appointment. The capital placed at his disposal was not enough to enable him to carry out his own ideas in all respects, and he was obliged to construct a railway without interfering with the many heavy gradients of the ordinary roads of the district. On a steep gradient a locomotive engine would be liable to two disadvantages from which it is free on a level road: in the first place, the pressure upon the rails is diminished, and there is therefore a greater tendency towards slipping between the wheels and the rail; and in the second place, the resistance to the moving force is very much increased owing to the heavy engine itself, as well as the trams or carriages, having to be lifted to a higher level. If a stationary engine is employed the first of these disadvantages is of minor importance, for the trams are hauled up whether the wheels revolve or not; and the second difficulty is obviated. For these reasons, notwithstanding their comparative clumsiness, stationary engines were adopted for moving the full trams up the steep gradients; in descending they were allowed to run down of themselves and to draw up the empty return trams on a parallel line. This railway was opened on November 18, 1822. A month before this, Robert Stephenson was sent by his self-sacrificing father to Edinburgh, for a short course of instruction in that University; he was away six months, at a cost of some £80.

For many years it had been felt that some outlet was needed for the immense supplies of coal which existed in the interior of the county of Durham. With the existing means of transport it was impossible to convey to the sea-coast and to ship those supplies at a price that could compete with that of sea-board coal. The coal in the interior was therefore practically locked up from the outside world, and could only be worked to advantage for local use. For some fifty years one scheme after another had been taken in hand to construct a canal, or a tramway, or to widen the Tees, so as to overcome in some way the obstacles to a profitable trade in inland coal; but the energy that succeeds was wanting to them all until Edward Pease, of Darlington, at last determined that something should be done. He had been willing to support a movement for a canal, but when he was in a position to take the initiative he decided in favour of a railway from the Bishop Auckland coal-field through Darlington to Stockton. There had been a public railway some twenty years before this from Wandsworth to Croydon; it was public in the sense that any one might put waggons on the line and carry goods within prescribed rates, the waggons being drawn by horses, mules, and donkeys; the undertaking in its results was rather a discouragement than otherwise to similar enterprises. All other railways had been constructed by colliery proprietors and used solely for their own purposes; in fact, they were private projects. They were, however, regarded by Pease as a series of experiments, the practical result of which had been a gradual improvement in their construction and management, and therefore in their prospects. What they had done on a small scale, he set himself now to inaugurate on a larger. The line from Bishop Auckland to Stockton was much longer than any of the lines already constructed. It was not to belong to a colliery company for the working of their own coal, but was started by an independent company for the general advantage of an extensive and rich coal-district. That it would be used by coal-owners there was little doubt, and this was one cause of local opposition. Such carriage as there was paid toll to the road-trusts of the district, and they were loath to relinquish their established interest in the transport. When alarms and fears began to spread amongst the mortgagees of the turnpike tolls, Edward Pease met their bewildered opposition by offering on behalf of the railway company to buy their securities at the prices originally given for them. His earliest scheme contemplated the employment of horse-power on the railway; for he had not made himself sufficiently acquainted with the few cases of successful locomotive engines to be convinced of their advantages; moreover, the sole object of the movement was to provide means of conveying coal to the sea-board, and, though the conveyance of other goods was mentioned, the thought of passenger traffic was not yet entertained by any of the promoters. In fact, in its inception the Stockton and Darlington Railway was to be merely a road laid with wooden rails, and the first fight was on the question whether powers should be granted for even this new departure in dealing with heavy public traffic. In the third year of trying, the Bill was at last passed through Parliament in 1821.

George Stephenson heard of these things, and had now acquired more experience in railway management and railway engineering than any one living. He was anxious to increase his experience and to leave the impress of his own ideas on any works of the kind that he could get entrusted to him. He did not desire appointments now for the sake of the position or for the sake of occupation; he longed to take part in the great development whose future he could better foresee, and whose success he could more certainly ensure, than any other man. His experience, too, had taught him confidence in the soundness of his principles and in the worth of his work. Accordingly he made a pilgrimage to Darlington to see Mr. Pease, announced himself as "only the enginewright at Killingworth, that's what he was," and asked to be appointed engineer of the proposed railway. Mr. Pease, from that and subsequent conversations, saw that he had found a man of sterling worth who knew what he was about, who was eminently practical, and who had had as wide an experience in railway work as any one whom he was likely to meet. He therefore strongly recommended the directors to appoint Stephenson as their engineer. This they did; and in taking this work it may be said that George Stephenson became the inventor of a new profession, of which he was himself the greatest ornament. The first thing he set himself to do was to show Mr. Pease his Killingworth locomotive, and to win him over to the adoption of it on the railway. With a man of Mr. Pease's shrewdness, seeing was believing, and the Act was in 1823 amended in this particular, and provision was made in it for passenger traffic. This was the first clause in any railway Act empowering the employment of locomotive engines for passenger traffic.

In the progress of this work, Stephenson, like Watt, was hampered by the unskilfulness of the mechanical labour upon which he was dependent for the construction of his engines. He proposed to meet the difficulty by establishing at Newcastle a manufactory for the building of locomotive engines, in which men might become accustomed to the work he required, and by the training of practice attain to some perfection in their art. He was himself able to devote £1000 to the object for this amount had been collected and presented to him by the coal-owners for his invention of the safety-lamp. Mr. Pease and his friend Thomas Richardson each advanced £500 for the same purpose, and in 1824 the works were fairly started.

In addition to the question of tractive power, the respective merits of cast and wrought iron rails had duly to be discussed—wooden rails were speedily dismissed from consideration. It would have been to Stephenson's immediate advantage if he had specified cast-iron rails for the line, on account of his own patent and his partnership with Mr. Losh, but his experience at Killingworth had convinced him of the superiority of wrought-iron rails, and he was not the man to be blinded in his counsel by an opportunity of putting £500 in his own pocket at the risk of bringing his judgment into disrepute. The cast-iron rails were constantly breaking under the stress of heavy traffic, and involved no end of expense for repairs and relays. The directors, however, on account of the great difference of initial cost, decided to lay only half the line with malleable rails, and the rest with cast iron.

All the forces of incredulity that ignores, of conservatism that hates, and of ridicule that mocks what is new were marshalled to oppose the work in which Stephenson was engaged. The idea that a train should be supposed capable of travelling *at a rate almost equal to that of the fleetest horse*, was represented to the readers of the *Whitehaven Gazette* as a most absurd extravagance; whilst to be dragged about by a *roaring steam-engine* was declared in the *Tyne Mercury* to be a treat for which no sane person would ever care to pay a farthing. Yet these preposterous and horrible schemes have now become everyday realities, and the roaring steam-engine a universal blessing, horrible no longer.

Opposition notwithstanding, the railway was completed, and opened on September 27, 1825, and the occurrence was a great event for the whole neighbourhood. The coal-waggons were fitted up for as many passengers as they could accommodate, and an engine of George Stephenson's own manufacture, driven by himself, was employed on the occasion. It succeeded in attaining a speed of fifteen miles an hour at the most favourable parts of the road.

The railway was not primarily designed to accommodate passengers, but to facilitate the transit of coal. One of its opponents, Mr. Lambton, afterwards Earl of Durham, hoped to embarrass the company by the insertion of a clause in the Act, whereby they were not empowered to charge more than a halfpenny a mile per ton for coal intended for shipment, under the impression that it would be impossible to carry coal remuneratively at so small a charge; this clause, however, turned out to be one of the happiest possible in its effect upon the success of the company, and before long the coal carried at this rate constituted the main bulk of the traffic, and was the main source of the company's prosperity.

Passengers were, however, not ignored. Stephenson built a car for them, called the *Experiment*, which reached Newcastle the day before the opening of the line. It is described as an uncouth machine, more resembling a showman's caravan than a passenger-coach of any extant form. A row of seats ran along each side of the interior, and a long deal table was fixed in the centre; the access being by means of a door at the back end, in the manner of an omnibus. It was not run by the company, but let to contractors, who employed one horse to draw it. This was the humble beginning, at the end of the year 1825, of our railway travelling.

Thus was this effort of Pease and Stephenson at length started on the lines of success. After this, the scene of Stephenson's labours was shifted to Liverpool and Manchester. Some improvement in the means of communication between these cities was urgently needed. The three canals and the turnpike road were unequal to the work required of them—traffic was blocked for days, and at times even for weeks; and, in addition, the rates charged for carriage of goods was excessive. As a consequence, trade suffered, and the mercantile classes yearned for some release, they knew not what, from their grievance. The moving spirit in the introduction of the railway between the two places was Mr. Joseph Sandars, with whom in the earliest stages of the undertaking was associated Mr. William James, of West Bromwich, an enthusiastic advocate of railways, and an engineer with considerable practice, but one whom misfortune followed so cruelly that he was obliged to forego participation in many of his favourite projects, and amongst others this of the Liverpool and Manchester Railway. The opposition to this measure, both in and out of Parliament, was more obstinate than that to the Stockton and Darlington Railway. The preliminary survey, from which the plans for the line had to be drawn up for submission to Parliament, could with difficulty be carried on against the determined and untiring opposition of the influential landowners and canal proprietors of the neighbourhood. The surveyors had days and nights of real adventure as they encountered colliers, gamekeepers, and cottagers, bent upon destroying their instruments and preventing the survey. They had to get the strongest fighter of the district to come and carry their theodolite for them, and even then it was not safe. They had to devise many an ingenious trick to get a few free minutes by night or day for a hasty survey of some of the most guarded estates, and considered themselves lucky if they got off with threats of the legal consequences of their trespass. A company was at last formed, and issued its first prospectus in October, 1824. Meantime Mr. James had become involved in such inextricable embarrassment that it had become necessary to appoint another engineer in his stead. The choice fell upon George Stephenson, whom Mr. James had himself visited, and with whose extraordinary merit he was thoroughly impressed. In fact, practical men everywhere, who were not blinded by professional jealousy, and who cared to investigate impartially the successes which he had achieved, began to discern that there was a power and a potency for far greater achievements in the "engine-wright of Killingworth."

The Liverpool and Manchester Railway Bill came before the House of Commons in the beginning of 1825. It was deemed prudent to proceed cautiously with the measure, to speak of it as though it proposed no very extraordinary advance upon the ordinary modes of carriage, especially as regards speed, and to stay some of the fated opposition by saying little about the passenger traffic. The opponents of the measure urged not only the old arguments of impracticability, directed against the speed which might be contemplated; they had an additional objection, owing to the difficulty, or, as they said, the impossibility, by any available means, of carrying a line of rails across the four miles of the Chat Moss between Liverpool and Manchester. George Stephenson was put into the witness-box when the measure passed into Committee of the House of Commons, and had to endure the insolence of the very able but unscrupulous ignorance that was retained to prevent the passing of the Bill. Not to run too great a risk of failure, he had to moderate the speed of his engines to three, five, or six miles an hour, and to exclude those "hypothetical" cases of twelve miles an hour from his general experience. Nicholas Wood, who in the year 1825 wrote a "Practical Treatise on Railways," maintained that if the intention of going twelve or fifteen miles an hour had been persisted in, not a single person would have believed it practicable, and the company would have lost its Bill. All imaginable difficulties were dwelt on and made the most of. "Suppose now," said one of the members, "one of these engines to be going along a railroad at the rate of nine or ten miles an hour, and that a cow were to stray upon the line and get in the way of the engine; would not that be a very awkward circumstance?" "Yes," replied Stephenson, with a twinkle in his eye, "very awkward—*for the coo!*"

One distinguished member of the bar, whose mind came to the consideration of the question without any bias due to a previous acquaintance with the subject, had the self-confidence thus impartially to deliver himself on Stephenson's proposal to carry the line over Chat Moss: "It is ignorance almost inconceivable. It is *perfect madness*, in a person called upon to speak on a scientific subject, to propose such a plan. Every part of the scheme shows that this man has applied himself to a subject of which he has no knowledge, and to which he has no science to apply." His own opinion as to the utility of railways may be gathered from the following unqualified statement—the statements of ignorance are generally more unqualified than those of truth or of careful thoughtfulness: "Any gale of wind which would affect the traffic on the Mersey would render it *impossible* to set off a locomotive engine, either by poking the fire, or keeping up the pressure of the steam till the boiler was ready to burst." It was declared that the value of land in the neighbourhood of Manchester alone would be deteriorated by £20,000. In fact, the railway would be an unmitigated evil if successful; but the whole scheme was so very wild that it ought to be exposed *in limine*, and excluded from the range of practical enterprise. In consequence of the strenuous opposition of men who did not hesitate to abuse Stephenson as a man without plan or fixed designs in his mind, as taking refuge in vagueness and thus evading the difficulties which they forced upon him, the Bill fell through for that year. It is true, however, that Stephenson's surveys were to some extent at fault, and that their faultiness was fully exposed under the searching enquiry; and it was this that was supposed to justify an advocate's indignation in pouring scorn on the "*gross ignorance of this so-called engineer*, who proposed to dig impossible ditches by the side of an impossible railway."

It was a considerable disappointment to Stephenson to meet with this defeat, and the disappointment was considerably enhanced when he learnt that the directors of the company had determined to take a step which they thought necessary in order to avoid one cause of failure in the succeeding year; this was the engaging of Messrs. George and John Rennie to be the engineers of the railway in his place. In the following year the Act was passed, and, owing to some difficulty in coming to terms with Messrs. Rennie, it was decided to reinstate Stephenson as principal engineer, at a salary of £1000 per annum. Then commenced his great engineering feat. It is not possible to give any adequate statement of the difficulty of the undertaking; it was a difficulty that would need to come within one's own experience in order to be fully appreciated.

As far as Chat Moss was concerned, Stephenson was the only one, either engaged in the work or not, whose heart never misgave him about his ultimate success in carrying the road across. The Chat Moss is an immense bog, apparently filling up a shallow basin of clay and sand, and swelling visibly during rainy weather. It was impossible to stand on it without sinking; but Stephenson saw that, just as a floating bridge or a series of connected rafts could be used for making a roadway over water, so here all the more would such a design be practicable, seeing that the bog was much less penetrable than water. A bridge on the level of the Moss, supported on piers, was proposed; but Stephenson maintained that this would be more difficult and more expensive than his own proposal, however discouraged his assistants might be by the difficulties of a work to which they were new, and for which they were therefore unprepared. And the discouragements were many. In the course of the work it was necessary to dig out a wide ditch on each side of the line of rails, in order to drain off some of the water and consolidate to some extent the foundation on which the roadway was to be laid; but almost as soon as a portion of the drain was dug out, the fluid bog flowed in and filled it up again, and it was only with great difficulty that water could be carried off by this method. It was necessary to have a solid embankment at either end of the Moss, and labour seemed for a long time almost to be lost in the endeavour to pour in dry solid matter for this purpose; for weeks and weeks they went on filling in without the slightest apparent effect, and the directors began to talk about abandoning the scheme and carrying the line round by some other route. But the confidence of their engineer inspired them with at least so much shadow of hope that they allowed him to proceed, and with this result, that on the 1st of January, 1830, the road across Chat Moss was finished, and, whether as regards ease of travelling or expense of construction, it proved as satisfactory as almost any part of the line. Briefly, the construction of the line was as follows: upon the surface of the Moss a matting of heath and branches of trees was laid, and in some places light hurdles interwoven with heather; this floating bed was covered with a few inches of gravel, on which the line was laid in the usual manner, and with as successful a result as Stephenson had predicted.

Amongst the other works connected with the undertaking, which in those days were considered as stupendous as they were unprecedented, were the tunnel which it was necessary to construct for a mile and a half under the town of Liverpool, and a deep cutting through the red-sandstone rock at Olive Mount. This cutting was the first considerable stone-cutting on any railway, and it is still one of the most formidable. It is described as about two miles long and in some parts more than a hundred feet deep—a narrow ravine or defile cut out of the solid rock; and not less than four hundred and eighty thousand cubic yards of stone were removed from it. Mr. Vignolles said it looked as if it had been dug out by giants. The difficulty of making level roads throughout the country was at once fully demonstrated—and overcome.

It must not be forgotten that, as the pioneer of railway engineering, Stephenson had not only to face the opposition of prejudice and of established interests, but he had also himself to drill workmen for the new work which he wanted; he could not find labourers able to do the work at once, and therefore he had to make his workmen as well as the railway—to make his tools before he used them. In this task he was as successful as in his management of mechanical difficulties; and his character displays, in contrast to that which James Watt's morbid self-consciousness ascribed to himself, a resolute and active disposition, an ability to struggle for his own with mankind, to control men and grapple with difficulties, which eminently qualified him for a great undertaking. From the work done in connection with the Liverpool and Manchester Railway, the science of civil engineering took an entirely fresh start; and many details of the scheme were *first experiments*, and as successful as any that followed in solving the new mechanical problems, which the conditions of railway construction, as conceived by Stephenson, could not allow to be evaded.

Although the Liverpool and Manchester Railway Company had obtained powers to employ locomotive engines, it was not till the railway was nearly ready that they decided to exercise these powers. The opposition to such a course was led by the scientific and practical men of the day, and backed up by the prejudice and blind fears of the general public, who conjured up the most fantastic of evil consequences if it were persisted in. It was George Stephenson against the science and experience of engineers the whole country through. Messrs. Walker and Rastrick were asked by the directors to examine the whole question and report to them on the advantages of employing locomotives or fixed engines. These two professional engineers of the highest standing were of opinion that fixed engines were preferable, and accordingly recommended the directors to erect them along the line of rail, at distances of about a mile and a half, to work the trains backwards and forwards. Stephenson was not, however, going to give in even for this; and at last he succeeded in obtaining the concession of a practical experiment. The directors offered a prize for the best locomotive engine that should conform to the following conditions, if conformity to them was possible:—

1. The engine must effectually consume its own smoke.

2. The engine, if of six tons weight, must be able to draw after it, day by day, twenty tons weight (including the tender and water-tank) at ten miles an hour, with a pressure of steam on the boiler not exceeding fifty pounds to the square inch.

3. The boiler must have two safety valves, neither of which must be fastened down, and one of them to be completely out of the control of the engineman.

4. The engine and boiler must be supported on springs, and rest on six wheels, the height of the whole not exceeding fifteen feet to the top of the chimney.

5. The engine, with water, must not weigh more than six tons, but an engine of less weight would be preferred on its drawing a proportional load behind it; if of only four and a half tons then it might be put on only four wheels. The company to be at liberty to test the boiler, etc., by a pressure of one hundred and fifty pounds to the square inch.

6. A mercurial gauge must be affixed to the machine, showing the steam pressure above forty-five pounds per square inch.

7. The engine must be delivered complete and ready for trial, at the Liverpool end of the railway, not later than the 1st of October, 1829.

8. The price of the engine must not exceed £550.

With these conditions the *Rocket*, the engine made for the purpose by George Stephenson, in consultation with Mr. Henry Booth, alone complied; three other engines took part in the competition on October 1, 1829. The *Rocket* combined all Stephenson's inventions already mentioned, together with Mr. Booth's suggestions for improving the multitubular boiler, and the trial of it on this occasion completely silenced opposition. The prize of £500 was accordingly awarded to Messrs. Stephenson and Booth.

The line was completed in a few months, and opened to the public on the 15th of September, 1830; and eight of Stephenson's locomotives, in sundry stages of continued improvement, were ready to take part in the procession on the great occasion of the opening ceremony. The day was marked by one sad accident, which showed the magnitude of the power which had just been bound over to the service of the world, and the caution and care that would be needed in dealing with it. Mr. Huskisson, one of the members of Parliament for Liverpool, and an ardent promoter of the railway, was struck down by the *Rocket*, and shortly afterwards died from the effects of the injury received. Thus the day that was recognized as one of national importance on account of the inauguration of the first real railway, was overcast by the occurrence of this first railway accident.

The practical success of the Liverpool and Manchester Railway soon made railways as desirable in the eyes of the public as they had formerly been objectionable or ridiculous; they offered conveniences and commercial advantages so lavishly, that adversaries were rapidly won over by the potent argument of their own interests. The many objections to railways had not been altogether fanciful and groundless; the difficulties that had been brought to the front were enough to tax the wit and energy of the ablest men of the time, and the dangers proved to be such as to make the whole world tremble at the news of them: but neither difficulty nor danger were enough to block the advent of a blessing endued like this with the power of overcoming difficulties incomparably greater than any that it presented, and obviating more dangers than it introduced. The railway system, when weighed in the balances, was not found wanting.

Though Stephenson was occupied to a considerable extent with railway engineering, and in constantly improving the engine or some other part of the machinery of the railway, yet he had a keen discernment to discover opportunities, and abundant energy left to avail himself of them. He had induced some of his Liverpool friends to subscribe the money for a much-needed line from Swannington to Leicester, with a view to improving the coal supply in this important manufacturing town, and his son Robert was appointed engineer of the undertaking. During the course of the work an estate near Snibston was offered for sale, and Robert had had sufficient experience of coal districts to see that the estate probably contained coal. In this view his father concurred, and, in conjunction with two friends, purchased the property in 1831. Shortly afterwards he took up his residence there, at Alton Grange, to superintend the mining operations. These were fully as successful as he had anticipated, and proved extremely useful to the town of Leicester; in fact, the price of coal there was diminished to such an extent that the inhabitants saved on their annual coal-bill an amount equal to the whole of their Government taxes and local rates. It would have been surprising if the colliery had been carried on without George Stephenson making some improvement in the operations, and in this instance there were special difficulties that called for an exercise of his mechanical genius. His various improvements were not jealously guarded secrets, but were freely explained to all, and must have had a beneficial effect upon mining in that part of the country. The village of his work-people was most liberally and kindly treated by him, their welfare was thoughtfully provided for. He had been a model amongst workmen, he was now a pattern amongst employers.

The immediate consequence of the completion and evident success of the Liverpool and Manchester Railway was to win over the most enterprising section of the community, and, through them, to create a demand for railways between other large towns and through manufacturing districts. But though the advocates of railways were continually increasing in number and influence, the severity of the battle they had to fight, and the intensity of the new opposition now roused to activity, seemed to increase as rapidly. It was natural that as much as possible of the railway operations commenced in various parts of the country should be entrusted to George Stephenson, as the first essential condition of their success. Had he not constructed works already which, in magnitude and difficulty, excelled those of the despotic monarchs of Egypt and of Babylon? Had he not set at defiance the knowledge and experience of professional engineers, and demonstrated that what to the foremost of them was impossible to him was possible? Had he not single-handed won the battle of the locomotive, "while all the world wondered"? The engineering difficulties of the new undertakings were even greater than those he had already overcome, new and unexpected obstacles due to the nature of the ground presented themselves, and were encountered with a determination peculiarly his own. The difficulties which arose in the course of the operations, and which would have turned aside any other man from the task, only served to develop in him fresh resources. The world of possibilities was to his mind much vaster than it appeared to any of his contemporaries, and when once he recognized the possibility of carrying any work through, he was not to be deterred by its difficulty. When tunnels were flooded, owing to an unsuspected bed of quicksand being cut into, a vast system of powerful pumps was designed and erected, and water enough drawn off to fill the Thames from London Bridge to Woolwich, in order to enable the workmen to continue the tunnel, and line it with good solid masonry to withstand the water in future. The bridges, the cuttings, and tunnels were proofs of an untiring and apparently unprecedented, but most wisely directed energy.

As soon as a railway was projected, there was always an encounter with the obstinate prejudice of landowners, and with the obstruction of the canal and road interests, born of fear and brought to quick maturity by despair. Robert Stephenson, who at times assisted and at times represented his father with an ability on which no higher or prouder praise can be bestowed than to describe it as hereditary, gives the following amusing account of a visit he made with a hope of conciliating one distinguished landed opponent:—

"I remember that we called one day upon Sir Astley Cooper, the eminent surgeon, in the hope of overcoming his aversion to the railway. He was one of our most inveterate and influential opponents. His country house at Berkhampstead was situated near the intended line, which passed through part of his property. We found a courtly fine-looking old gentleman, of very stately manners, who received us kindly and heard all we had to say in favour of the project. But he was quite inflexible in his opposition to it. No deviation or improvement that we could suggest had any effect in conciliating him. He was opposed to railways generally, and to this in particular. 'Your scheme,' said he, 'is preposterous in the extreme. It is of so extravagant a character as to be positively absurd. Then look at the recklessness of your proceedings! You are proposing to cut up our estates in all directions for the purpose of making an unnecessary road. Do you think for one moment of the destruction of property involved in it? Why, gentlemen, if this sort of thing is allowed to go on, you will in a very few years *destroy the noblesse!*'

"We left the honourable baronet without having produced the slightest effect upon him, excepting perhaps that we had increased his exasperation against our scheme. I could not help observing to my companions as we left the house, 'Well, it is really provoking to find one who has been made a "Sir" for cutting that wen out of George the Fourth's neck, charging us with contemplating the destruction of the *noblesse*, because we propose to confer upon him the benefits of a railroad.'"

The particular railway here referred to was the line from London to Birmingham through Rugby, of which Robert Stephenson was the engineer-in-chief. It was on this line, at the Kilsby tunnel, that the pumping operations had to be resorted to, of which mention has already been made, and in consequence of which the original estimate for the cost of the tunnel was more than trebled. It is probable that the alarm of timid supporters must have caused some anxiety in the minds of those entrusted with the work, some fear lest the company should withdraw from the undertaking when they found the cost of every particular increasing so enormously beyond their expectations. The parliamentary expenses came to £72,868, the compensation to landowners went up from one quarter to three-quarters of a million sterling; these, apart from the engineering difficulties, with their immense attendant expense, were enough to cool the ardour even of enthusiasm; but the work was suffered to go on, for the promoters of it, though drained of more capital than they had anticipated, were by no means drained of their confidence in the skill and capability of the Stephensons, or in the utility and ultimate success of the undertaking. The Bill for it was passed in 1833, the line was completed and opened for traffic in September, 1838, and in this year the mails were authorized to be conveyed by rail.

The numerous schemes of railway enterprise that followed the Liverpool and Manchester undertaking showed that the well-fought fight had resulted in a battle well won. The Grand Junction between Warrington and Birmingham was opened in July, 1837; the Birmingham and Derby in 1839; the Midland in June, 1840; the York and North Midland in the same month; the Manchester and Leeds in March, 1841: so that in a few years all the ordinary routes of travel were supplied with railways, which were speedily much used in place of being much abused, and even the leaders of obstruction soon found themselves accepting the opportunities thus offered to them. Amongst these was Colonel Sibthorp, a member of Parliament, who made himself notorious not only by the extravagance of his opposition to railroads, "those infernal roads," as he called them, but also by his dogged resistance to free trade, and, some years later, by the violence of his denunciations against the Great Exhibition, of which he declared that when free trade had left nothing else needed to complete the ruin of the nation, the enemy of mankind had inspired us with the idea of the Great Exhibition, so that foreigners who had first destroyed our trade might now be enabled to corrupt our manners by their evil communications. Yet all these objects of his terror came steadily and surely on, have been carried to a great success on the flood of universal appreciation, and the advantage to the nation is much every way. We cannot help feeling some compassion for men of Colonel Sibthorp's disposition who were unfortunate enough to live in those days of great and rapid changes, all of which must have displayed to his mind the prospect of lower deeps beneath the lowest depths, still threatening to devour him, opening wide. Railways, a Reform Bill, the penny post, electric telegraphs, free trade, and the Great Exhibition, all forced their way to what these men could but regard as a disastrous success. It was some time, however, before all classes availed themselves freely of the conveniences of railway travelling. The Duke of Wellington, who had witnessed the fatal accident to Mr. Huskisson at the opening of the Liverpool and Manchester Railway, could not be induced to travel by rail for many years. The Queen's first railway journey dates from the year 1842, though the Prince Consort had for some time been accustomed to resort to the new means of conveyance.

In the midst of his extremely arduous engineering work, George Stephenson found time for extensive coal-mining in the neighbourhood of Chesterfield; for establishing lime-works at Ambergate, on the Midland Railway, which "were on a scale such as had not before been attempted by any private individual engaged in a similar trade;" and for occasional visits to his locomotive manufactory at Newcastle, which was in a flourishing condition.

From England, the fame of Stephenson, his locomotive, and his railway, rapidly went out into all lands. In Belgium, King Leopold was the foremost in discerning the merits and promoting the construction of railways; at his invitation Stephenson made several visits to Belgium to advise in laying out the national lines of the kingdom. Here he was fêted and held in unexpected honour. The King appointed him by royal ordinance a Knight of the Order of Leopold; he was invited to dine with ministers of State, and with the King and Queen at their own table; people thronged to see and applaud him. At a subsequent visit to Brussels, in 1845, the engineers of Belgium gave a banquet in his honour. At one end of the room was his bust on a marble pedestal, crowned with laurels; on the centre table, under a triumphal arch, was a model of the *Rocket*. This was a graceful compliment fully appreciated by Stephenson.

A journey to Spain was also undertaken, to effect a preliminary survey of a proposed line from Madrid to the Bay of Biscay; but the indifference of the Spanish Government, and the doubtful prospects of sufficient traffic, took the life out of the enterprise, and it was not entered upon.

The line from Chester to Holyhead was begun by George Stephenson, and carried to completion by his son Robert, who designed the tubular bridge across the Menai Straits. The navigation of the Straits was not allowed to be interfered with even during the construction of a bridge, and therefore piers and arches could not be used; the principle of suspension was inapplicable, and the idea of a hollow iron beam through which the train might run occurred to Robert Stephenson as a solution of the difficult problem, and proved to be successful. The two tubes, of which the bridge was to be made, were of wrought iron, and when they were ready they were floated out into the Straits and elevated into position. All this George Stephenson did not live to see; the few remaining years of his life, after his return from Spain in 1845, were spent in quiet enjoyment at Tapton; he withdrew from professional work almost entirely, busying himself, however, with his collieries and lime-kilns, and, as much as anything, with his garden, in the cultivation of which he was successful, and as pleased at his success in these ordinary aims as he had been after the worrying struggles that preluded his grandest achievements. Like James Watt, he was able to find interesting "hobbies" enough to make life worth living. He had fully earned the peace and the praise that crowned his latest years; and if toil unceasing, determined struggles, and unremitting activity make a man "half in love with easeful death," surely George Stephenson passed without regret for the past or dread of the future to a well-won repose.

He died on the 12th of August, 1848, in the sixty-eighth year of his age, from an attack of fever. He lies buried at Trinity Church, Chesterfield.

In contemplating the magnitude of his undertakings, and of his achievements that were fully commensurate with them, we are, perhaps, apt to overlook all the excellences of a character that must have made him welcome everywhere. There was a simplicity and a candour about him that expressed itself at times in the queerest way, and a shrewdness and humour about his conversation that made him the pleasantest of companions. His experience of human life, rough and trying and full of difficulties as it was, had no power to drag him down to a lower level than that on which he started. Many a man, amidst the excitement of continual action, is tempted to forego some high principle which has been the basis of his purest and earliest dealings with the world, but of Stephenson we may say that he was

> "The generous spirit, who, when brought
> Among the tasks of real life, hath wrought
> Upon the plan that pleased his childish thought;"

and if ever there was a man who, beset with anxieties and worried in the performance of his great undertakings,

> "Turns his necessity to glorious gain;
> In face of these doth exercise a power
> Which is our human nature's highest dower;
> Controls them, and subdues, transmutes, bereaves
> Of their bad influence, and their good receives,"—

surely that man was George Stephenson, the enginewright of Killingworth.

Common sense, schooled by a strong will, a natural fearlessness of thought and of speech, discernment, thoughtfulness, mental and physical robustness, these were the equipments by means of which he succeeded in leaving to the world as rich a heritage as it has ever received from the energy of one man. It is marvellous how quickly we have entered into possession—proof enough that the mission which fell to his lot was one for which the world waited. He endowed us with a powerful instrument of civilization, effective first of all in our own country, and then conferring like blessings the whole world round. Men who think have noted and proclaimed the vast social results of his labours. Dr. Arnold, of Rugby, said, when he saw the railway train speeding over the country, "I rejoice to see it, and to think that feudality is gone for ever: it is so great a blessing to think that any one evil is really extinct." It is a good thing to break down the barriers to communication between town and town, but the railway had, besides, the social effect that it broke down many of the barriers to intercourse between different classes of society; all, from the highest to the lowest, used its advantages, and were brought into occasional intercourse with one another, and this is what Arnold saw and praised. So Carlyle speaks, in his rugged way, of the steam-engine "rapidly enough overturning the whole system of society; and for Feudalism and Preservation of the Game, preparing us, by indirect but sure methods, Industrialism and the Government of the wisest." In far-off India, too, the advantages of the railway are recognized, and we know not what social liberty may there be introduced when that country is gradually freed from the oppressive restraints of the caste system, as we have been delivered from a feudalism which England once loved and clung to with persistency. The rough places have been made smooth and the crooked straight in external nature; and the same agency may tend to produce the same effect in social life; and the wisest and best, instead of being suppressed, will be available for the service of their country and of the world, whether their original rank in life be high or low. But there is no end to the indirect benefits which may be derived from the successes of Watt and of Stephenson; each of them has, however, left the world a heritage the prospective increase in whose value passes present powers of calculation.

CHAPTER IV.

SIR RICHARD ARKWRIGHT.

ON the 23rd of December, 1732, there was born at Preston, in Lancashire, of the poorest parents, and the youngest of a family of thirteen children, a boy gifted by grace of great Nature, or design of greater Providence, with ability, clearsightedness, and energy that should lift him far from the humble level of his birth, and give him a crown of honour, and us a very welcome harvest of profit and daily comfort. Richard Arkwright was taught little, if anything, when a lad except the business of a barber, which he carried on with such success as offered at Bolton ; it is certain that in the pursuit of this lowly calling he kept his mind active by the exercise of his thinking faculties, and was on the alert to turn to his best account anything upon which, by attention to what he heard or ingenuity in what he devised, he might happen to chance. When some twenty-eight years of age he gave up his business as a barber, and became an itinerant dealer in hair, for he had become possessed of a secret which promised a man of his quickness and "go" better prospects than his monotonous shaving and haircutting: it was nothing more than a method for dyeing hair and for preparing it to be made up into wigs. So he passed from one humble calling to another almost as humble. Before this he was probably as well off as most itinerant dealers in hair of his rank, but this first decisive step of his was enough to show that he could be dominated by an idea even to the length of relinquishing some certainties of advantage, and that he had the determination to push his idea through to such success as it was capable of. Soon he acquired a reputation through all the country round for the excellence of the hair he supplied. And had he not ideas, perhaps even now, foreshadowings at least of many that he afterwards shaped into definiteness and usefulness? Says Carlyle, "Nevertheless, in stropping of razors, in shaving of dirty beards, and the contradictions and confusions attendant thereon, the man had notions in that rough head of his! Spindles, shuttles, wheels, and contrivances, plying ideally within the same; rather hopeless-looking, which, however, he did at last bring to bear. Not without difficulty."

His wanderings very probably gave him further opportunities of picking up stock-in-trade, to hand over as prepared material to wig-makers, than he would have had if he had remained at anchor in his little barber's shop at Bolton; and the owner of such precious secret as his could make more by it than by shaving for one penny. Was his ambition, then, to become a wig-maker as soon as sufficient profits should accrue to start him in that higher business, when, too, he would not have to pay others to supply him with dyed and prepared hair, but could take to himself the profits of both trades? Not unlikely; and, but for the fact that in wandering from place to place he picked up much beside hair for wigs, of which, too, he was able to make use, and prepare for the use of other manufacturers than those of wigs, he might possibly have lived an obscure successful life with much credit in the small range of its influence, but without any extraordinary service or interest to the world. But whilst he was doing his unexciting work of preparing orderly cover for the outside of other men's heads, he was—apparently, too, without much mental excitement—introducing order and exercising thought in the interior of his own; in consequence of which it appears that, whatever he did in those days to cover the heads of thinking and thoughtless men and women with a fair show of hair, he has done more for us in providing for the inside of ours some furniture of profitable thought when we come to read about him, to consider the character of the man, and to search out the secret of his successful progress through life from small beginnings to a proud issue.

His itineration carried him about amidst the villages of South Lancashire and Cheshire, in the district of cotton-spinners. In their work some great improvements were at this time being introduced. There was a poor and illiterate but ingenious weaver, James Hargreaves by name, who had invented a very efficient machine for doing the work of many spinners; this machine was his now celebrated spinning-jenny; it was really a contrivance by which many spindles arranged suitably in a frame could be worked together by turning an attached flywheel. The rovings of cotton passed under a bar-clasp which served the purpose of the spinster's finger and thumb for all the spindles at once, and which could be moved backwards and forwards on a rail in the manner of the spinster's hand when stretching the thread and winding it on, but with an undeviating precision of motion which ensured a greater regularity in the spun thread. This was a labour-saver of the first importance, and entitles the inventor to the warmest praise. Not so, however, thought the spinners of his district when at last they found out that Hargreaves was spinning more and toiling less than they by the use of the machine, and easily supplying his own loom with all the woof required instead of keeping some three or four spinsters at work in order to obtain the full supply. It was looked upon by those who earned a living by spinning, as though it would dispense with their labour; they behaved as though all their labour would not still be wanted to turn the handle of the jenny, and that, too, without using up all the available supply of cotton. The opposition to the jenny and its inventor is intelligible enough, even as ignorance and panic fear are intelligible and common phenomena; but it would only have been excusable if the world did not require and would never need more cotton than was being spun at the slow old-fashioned speed with its wasteful expenditure of human labour, and if no other work could be found for those immediately thrown out of employ by the jenny. We are wiser now by a hundred years of very convincing experience. Nothing can to us be more certain or more demonstrable by abundant instances than the happy fact that the inventions of genius and the discoveries of science have constantly required an expansion and not a contraction of human labour. Cotton goods were, before the days of Hargreaves and Arkwright, luxuries coveted by thousands whose wishes were denied merely by the heavy cost of the goods. With a cheaper production there was at once a corresponding increase in demand; and the man who made it possible for the masses of the population to partake of a comfort hitherto enjoyed by the wealthier few deserves to be honoured as the poor man's friend and benefactor, not persecuted as his foe. In the words of Thomas Savery, he might have said, "My design is not in the least to prejudice the artificers, or, indeed, any other sort of people, by this invention, which, on the contrary, is intended for the benefit and advantage of mankind in general."

Opposition and violence notwithstanding, spinning-jennies, at least smaller ones fitted with some fifteen or twenty spindles, began soon to be tolerated and at last to establish themselves; the jealous and furious ignorance that drove Hargreaves from Lancashire to Nottingham spared, with an unusual discrimination in its madness, the smaller machines when the larger were ruthlessly destroyed. Nowadays we are not so inclined to stand in fear of the sudden effects of such industrial changes. We are beginning to believe that while it is well that transitions should not take place with startling rapidity, so also it is in the nature of things that they do take place and manifest their effects gradually. Let us move as fast as we will towards any desirable improvement we choose, there will, independently of us, be provided drags and impediments enough to secure that the change shall be as gradual as is needed.

This of Hargreaves' was the first successful attempt to devise any improvement upon the time-honoured spinning-wheel in the spinning of cotton, and dates from the year 1767, though the inventor himself seems to have used it in secret as early as the year 1764, being actuated to this secrecy more by fear of violence than by greed of gain. Some thirty years earlier a machine was invented for a different object, namely, not only to spin more but to spin stronger yarn, by Wyatt and Paul, of Birmingham; but there was in it some one defect or other, and it brought its inventors and friends misfortune instead of the expected fortune. It is said by some that the specification of this invention, which has been published, shows that the principle upon which it was based was akin to that afterwards adopted, developed, and applied by Arkwright; it has even been suggested that his own invention was an unacknowledged adaptation of the earlier device. This charge is very fully investigated and refuted by Dr. Ure, the historian of the cotton manufacture of Great Britain. Paul's specification is either obscure or unmeaning; at any rate the meaning that would naturally attach to its wording is such as to win ridicule rather than admiration, and to account for the ruin which the invention brought upon its promoters. One leading feature of Paul's first patent was a "fantastic whim of successive rollers with certain whirligig inexplicable motions," which were put in the specification "like the Martello Towers on the Irish coast, for the purpose of puzzling posterity." In addition to all that Dr. Ure urges in favour of the independence of Arkwright's invention, it may be held likely that an unbookish itinerant dealer in hair was not quite the sort of person who would be expected to pore over the most inaccessible books for hints which he might turn to best practical account, or to search in them for inventions to be supplied and fitted up with the missing requisites for success. Even had he done this, great enough would have been the glory, and greatly would his merit deserve to live on from man to man.

It is an unworthy task, too often undertaken, to detract from the worth and fame of men who have lived the benefactors of their country and the world, but at least the attempt to do so may lead to the re-examination of claim and counter-claim, and in the end increase the honour where the honour is due; and so it has been in the case of Arkwright.

Before this time pure cotton fabrics were not made in England; the fustians that were manufactured had a warp of linen yarn, owing to there being then no known way of spinning cotton yarn of sufficient strength. Arkwright in his wanderings soon became acquainted with the difficulties that beset the manufacture of cotton goods, arising from the absence of cotton warp and the deficiency of cotton weft; as well as with the partial remedy of this latter evil by the contrivance of the spinning-jenny. He was of a mechanical turn of mind himself, and thought that the force of contrivance might still further go, and set himself to devise and to test some machinery which should serve to meet both the difficulties which embarrassed the weaver. He had not had opportunity for acquiring mechanical skill to help out his mechanical ability, and had therefore to employ a clockmaker, named Kay, to construct his machines for him. He gave out, in the first instance, that he was busied at the solution of that will-o'-the-wisp problem of perpetual motion —a problem by which he may have been fascinated and occupied; but it is a plausible suggestion that this announcement was merely a blind to divert attention from the real object of his labours. He would probably prefer to bring his work to some satisfactory stage of success apart from the interference of the public gaze, which would be sure to be attracted to so important an undertaking as that which he was contemplating; and at the same time some hint might be purloined from him and quickly developed by some sharp-witted spectator, who would thus take out of his hands the success for which he was striving, and deprive him of his well-merited reward.

Whether perpetual motion or spinning of cotton occupied his thoughts, he soon found a far more absorbing interest in his mechanical contrivances than in his bartering for hair, and in the year 1767 he withdrew from this calling, not, we may be sure, before he had attained to a shrewd confidence that he could make a better career for himself in some other way. It is a short matter to read and acquire a knowledge of the principle of a machine, it is a longer task to become thoroughly acquainted with the practical working of it, and it is a longer task still for a man to devise the machine, and develop it from the first rude suggestion that strikes his mind, till it is freed from its impracticabilities and brought to the desired serviceableness. Already a fair idea of his plan for spinning cotton by rollers had taken definite shape in Arkwright's mind; it was not merely an ingenious modification of the methods then in use, it was the introduction of a principle new to this industry. He himself said that the first hint of his invention occurred to him as he was watching a red-hot iron bar lengthened out by passing between rollers. But it was even then no very self-evident proposition that what was possible with iron was possible with cotton wool as well. In fact, means had to be devised for compelling the cotton wool to behave as the red-hot iron naturally behaved in passing between a pair of rollers; that it too might be elongated at the same time that the diameter of the thread was diminished. For the practically incompressible iron rod there was no choice left; if it became thinner it necessarily became longer; but the cotton wool admitted of much compacting together, and unless taken hold of, and forcibly stretched as it passed through the pair of rollers, it would be compressed but not drawn out. It should also be remembered that iron is pressed and drawn between rollers primarily for the sake of refining and toughening it, for during the operation a great quantity of scoriaceous matter which is retained after passing through the puddling furnace is squeezed out, and the iron assumes a fibrous structure, possessing the malleable and ductile qualities of wrought iron. Thus both means and end in the application of rollers to cotton-spinning were different from those of the iron manufacturer in his application of them. Arkwright's invention consisted in the use of two pairs of rollers, called drawing-rollers, the first pair revolving slowly in contact with each other, the second pair more rapidly in a similar manner. One roller of each pair was covered with leather, and the other was fluted longitudinally,* and the two were pressed together by means of weights; the object of this was to secure the adhesion of the cotton wool, so that the rollers might not slip round without drawing it in. Through these two pairs of rollers the cotton passed, and the extension to which it was subject in the process depended on the difference in the velocity of revolution of the two pairs. The requisite fineness being obtained, the cotton, as it passed from the second pair of rollers, was twisted into a firm strong thread by spindles attached to the frame.

The cotton plant, or *gossypium*, is of the natural order of the mallows; the seed is enveloped in a filamentous down, usually white but occasionally yellow. This down is thus described by Dr. Ure:—

"The filaments, when viewed in a good achromatic microscope, appear to be for the most part riband-formed or flattened cylinders, with a thickened list at either edge, and veins of embroidery running along the middle. They vary in length from half an inch to one inch and three quarters; and in breadth from one seven-hundredth to one twenty-five-hundredth of an inch, tapering always to a fine point at their ends. These variations in length and breadth belong to plants of different growths and countries, the filaments being pretty uniform in the average product of each particular crop. The lustre of cotton, as seen in the microscope, is pearly, whereas that of flax is vitreous. Whether a cylinder or a riband, the cotton fibre is seldom or never straight like that of flax, but is either twisted right and left or coiled like

* The drawing rollers for rolling iron bars are grooved in the direction at right angles to this, *i.e.*, round the circular circumference of rollers, and for a different purpose, namely, to regulate the size of the rod.

a corkscrew. Those of the best Sea Island, the most valuable species of cotton, very commonly appear to be beautiful spiral springs, singularly adapted to the spinning process, readily entwining with and sliding over each other, during the formation of a thread, with an easy elastic force. There are no feathery margins, as some writers have described."

It should be borne in mind that, in the process of spinning, the separate fibres of the cotton wool are not stretched—they are scarcely capable of extension. The rollers, therefore, must not be nearer to one another than the length of the fibres. The thread is lengthened by the slipping of fibres along one another, and their roughness and spiral form make them cling to one another and form a continuous thread.

From the beginning it was necessary that Arkwright should seek some assistance to enable him to carry out his invention. Immediately on the construction of his first model he applied to a Mr. Atherton for the help he needed, but with no great success. Mr. Atherton, indeed, sent him two workmen to assist Kay in the construction of the machine, but did not care to venture further in support of an untried and hazardous experiment, by which he thought much money might be lost. The two workmen were at once set to work, and the first machine was soon completed. With this, Arkwright repaired without delay to Preston, his native place, and, owing to the services of John Smalley, a liquor merchant and painter, he was able to set up his spinning-frame and commence operations with it in a room of a house belonging to the Free Grammar School. Here he practically put his perfected machine to the test of experiment, and with so fair success that he and Smalley were both convinced of its excellence and usefulness, and determined to see how they might profit by an extensive use of it. They were also aware of the results of other Lancashire experiments, and remembered that a bevy of infuriated spinsters had very recently burst into Hargreaves' house and in their jealousy destroyed his spinning-jenny. They considered that, in such peaceful occupations as theirs, prudence was to be chosen before valour, and decided to betake themselves with their machine to another part of the country. Like Hargreaves, they turned to Nottingham, the centre of the framework stocking trade.

The manufacture of cotton hosiery had hitherto been carried on on a very limited scale, owing to the difficulty of obtaining yarn of proper strength for use in Lee's stocking-frame. This was evidently Arkwright's opportunity, and he had the sagacity promptly to avail himself of it. He and Smalley were first associated with Messrs. Wright, Nottingham bankers; but estimating the success of the present enterprise by analogy with that of Wyatt and Paul, instead of by reason on its own merits, these capitalists withdrew from it. Worthier substitutes and stauncher friends were, however, found to take their place, in Mr. Samuel Need, a considerable manufacturing hosier of Nottingham, and his partner, Mr. Jedediah Strutt, of Derby, the inventor of the chief improvement made in Lee's stocking-frame—that for making ribbed stockings. These, being practical, successful, and ingenious men, were well qualified to form an opinion about the merits of the new spinning-frame; and the embarrassments which at that time hindered the development of the manufacture of cotton stockings made them eager to examine any novelty which promised to supply a stronger yarn. Their verdict was wholly in favour of the invention, and they became to Arkwright the counterpart of Boulton to Watt.

The very year that Watt patented his "fire-engine" with a separate condenser, Arkwright obtained his first patent. Two years afterwards, in 1771, in conjunction with Messrs. Need and Strutt, he established a factory at Cromford, on the Derwent, far more complete in design and equipment than his earlier factory at Nottingham. At Cromford the original frames of the inventor were in use for many years; they were still at work when Dr. Ure wrote his "History of Cotton Manufactures," affording, as he says, proofs demonstrative, were any wanted by the candid philosopher, that Arkwright was no plagiarist of other men's ideas, since he had then created a grand productive automaton, unlike anything else on the face of the earth. Even stronger evidence of his originality in great concerns is furnished by his undoubted originality and inventiveness in the small details of the machine; if we trust him for faithfulness in few things and small, we may also consider him trustworthy when he claims the credit of originality in his greatest achievements.

We learn that many years of indefatigable labour passed while he was bringing to perfection his factory system, and that scarcely a week passed without his being able to record some new improvement in the machinery or management of his enterprise. We do not hear enough of Arkwright nowadays, and are apt to grow into the belief that he did little beyond inventing his spinning-frame. This first invention was indeed the seed-sowing for his life's harvest, but he did not reserve himself entirely, and without further exertion, for the harvest of his early pains and hopes; with constant attention and care he tended its growth, and by his intelligent cultivation of it caused it to bring forth manifold more than it would otherwise have done. These years at Cromford were most like those busy inventive years of Watt at the Soho Works, when his steam-engine was beginning to come into general use throughout the country. The factory at Cromford, like Stephenson's engine at Killingworth, came to be one of the wonders of the neighbourhood. The good people of Leigh, where Arkwright was well known, used to visit and take their friends to see what marvellous things were being done in their midst, to whose merit they were by no means blind; and after seeing the machines at work they would buy a dozen or two of pairs of stockings made of yarn spun by them—a very useful memorial of their visit.

Arkwright's success excited the envy, and indeed the malice, of the Manchester manufacturers of the ordinary English mixed goods; and although the excellent water-twist spun on his spinning-frames on the banks of the Derwent was admirably adapted for use as warp, and so for supplying the demand for genuine cotton goods without the inconvenience and expense of importing them from India, yet the manufacturers refused to give to an ingenious mechanician, whom they regarded as a rival, even the encouragement of purchasing from him the yarn which he alone could supply, and which was the great desideratum in their business. On account of this there was no market open to the water-twist, and it was left to accumulate on the hands of Arkwright and his partners. They were naturally driven to use it themselves, and this they first did in the manufacture of stockings, as we have already seen. But in the year 1773 they commenced to employ it in the manufacture, for the first time in England, of fabrics consisting wholly of cotton. The introduction of this manufacture is an epoch in the industrial history of the kingdom; the trade thus founded has shown capabilities of rapidity of expansion beyond the most extravagant dreams of its promoters, although Arkwright himself was one of the most sanguine of men, and loved to dwell upon the merits of his many inventions with an enthusiasm that amused the incredulous, and even annoyed his friends. It might fairly have been thought that from that time England would be able to supply her own demand, and would no longer be dependent upon the looms of India for her cotton goods; it could perhaps scarcely have been expected that goods of English make would find their way into all the large markets of the world, and would even make markets for their disposal in remote regions of Africa and in the wild and inhospitable tracts of Central Asia. This result must be largely attributed to the determination which actuated the illustrious founder of the trade, whereby he was able successfully to establish his inventions, and to show how they might to best purpose be employed in efficient factories.

Some further considerable trouble was caused to the nascent industry at the outset by certain laws whose professed object was to put foreign goods at a disadvantage in comparison with home manufactures; and this trouble was augmented by a fresh display of the narrow-minded jealousy of the Lancashire manufacturers. Apparently under the modest impression that the clumsiness of our countrymen's handiwork could never be expected to match the perfection of Indian achievements, and that no great improvements in our cotton-spinning need be anticipated or provided for, it had been enacted that calicoes (Indian cotton goods originally imported from Calicut, whence their name) should be liable to a duty of sixpence per yard, the duty on the English mixed goods being only one-half of this; moreover the sale of such fabrics when printed was prohibited. The numerous orders executed at the Cromford Mill were suddenly countermanded, owing to the higher duty being unexpectedly demanded by the excise officers, who maintained that the materials were still calico, even though manufactured in England. An application was at once made to Parliament for the repeal of an Act so injurious to a promising and welcome industry, and, though finally successful, it was rendered tedious and expensive by the bitter opposition of those same Manchester manufacturers, who should naturally have been its most ardent supporters. But if a little personal hatred gets into the human heart it is apt to blind it even to its own interest.

In 1774 the desired repeal was obtained, cotton and mixed fabrics were made alike liable to a duty of threepence per yard, and the prohibition on printed cotton goods was withdrawn.

Arkwright's second patent is dated 1775, the year of the extension of Watt's patent by Act of Parliament, and comprises the results of several years' hard thought, with adjustment and readjustment of contrivance in all branches of the cotton-spinning trade. A most comprehensive patent it was to publish to the world; probably no other has ever contained so many distinct mechanical inventions subservient to a common end. In brief, it was a patent for a cotton-factory. A variety of ingenious machines were invented to improve the mode of preparing the cotton for spinning—"carding, drawing, and roving machines for use in preparing silk, cotton, flax, and wool for spinning." Dr. Ure describes the patent as embracing the whole train of operations in a complete cotton-factory, admirably arranged in subordination to each other. But the inventor had to carry his inventions to success in practice, to drill workmen and workwomen into the discipline of the factory in place of the independence and freedom of isolated labour, to insist upon cleanliness and order and regularity in all the round of work. This task was akin to that of Stephenson's when he undertook his "impossible" engineering operations of the Liverpool and Manchester Railway, or to that of Columbus when in mid-Atlantic he confirmed his stubborn resolution to go on over the trackless sea, "through clouds that mutter, and o'er waves that roar." It was the task of convincing or compelling men to place reliance on his idea, and submit their wills to his. By inventions he had bent inert Nature to his service, and taught her some profitable lesson of obedience; by force of character he became an acknowledged lawgiver to his work-people, and bent them to work in a way which he saw would increase the efficiency of their labour. He thus established a cotton-factory which served as a pattern for all others. Can we help thinking that Arkwright, after seeing that the energy and capabilities of nature and matter could be best directed when restricted to the narrow freedom allowed by a machine, must have entertained this thought too, that the wayward energies of men and women would likewise be used to the greatest effect if they could be made, whilst within the factory walls, to work with the precision and with the obedience of machines—"theirs not to make reply, theirs not to reason why"? As far as the mass of work-people are concerned such thought is probably right. It is curious that at this very time Adam Smith was impressed with the same thought, and urging it upon the consideration of the world from the philosopher's side, when he reasoned of the advantages of "the division of labour." This is, of course, a principle that has always been recognized by practical men since "Adam delved and Eve span," but it had been but little applied to the manufacture of cotton, till Arkwright turned his attention to the problem. He found this manufacture uncertain, languishing, and embarrassed by difficulties that were to it as the thorns to sown wheat—like to choke it entirely; he freed it from its difficulties, gave it new life, and endowed it with a stability which has enabled it to become one of the chief pillars of our national wealth.

It is indeed remarkable that all this should have been accomplished by a man without education, either in the subjects of schools or the practice of workshops, a man untrained for the works of invention and of organization which he took in hand in so masterful and successful a manner, and sprung from the lowest ranks of society to demonstrate how genius can rise superior to all difficulties, and how irrepressible the true sort is. Even for the natural kings of men, endowed with the rare qualities that urge them to give to the world royal gifts of comfort and of happiness,—even for these, the road to the success upon which their heart is set is no royal road; but theirs is the greatness to recognize the difficulties only to obviate them, and still to press on to the attainment of a clearly defined hope. In fact, the one common characteristic of the band of heroes whose lives are now furnishing us with subject of admiration and of thought, is that from the beginning they had clear ideas about some desired object, and about the means for attaining their so devoutly wished consummation. The indulgence of vague hopes, and the contemplation of fanciful realizations may make a Mother Shipton, but never a Watt or a Stephenson,—they may make dreamers and wonderers and interesting story-tellers, but not workers to leave an evident impress on the material environment of human life.

The celebrated Dr. Erasmus Darwin, who lived during this period of wonderful mechanical progress, and was acquainted with the inventor of the separate condenser, as with most other men of note at that time, gives a careful and graceful description of the various strange processes introduced at Cromford:—

"Where Derwent guides his dusky floods
Through vaulted mountains and a night of woods,
The nymph *Gossypia* threads the velvet sod,
And warms with rosy smiles the wat'ry god;

His ponderous oars to slender spindles turns,
And pours o'er massy wheels his foaming urns
With playful charms her hoary lover wins,
And wields his trident while the Monarch spins.
First, with nice eye, emerging Naiads cull
From leathery pods the vegetable wool;
With wiry teeth *revolving cards* release
The tangled knots, and smooth the ravell'd fleece:
Next moves the *iron hand* with fingers fine,
Combs the wide card and forms th' eternal line;
Slow with soft lips the *whirling can* acquires
The tender skeins, and wraps in rising spires:
With quicken'd pace *successive rollers* move,
And these retain, and those extend, the *rove;*
Then fly the spokes, the rapid axles glow,
While slowly circumvolves the labouring wheel below."

Amongst the many disadvantages under which Arkwright laboured in bringing his designs to perfection, it is no trifling circumstance that during these years of toil he was afflicted with a most troublesome asthma, which seemed again and again almost to have worn out all his physical strength. It might now be imagined, that after all this toil, this absolute devotion to the perfection and realization of a practical aim, a sacrifice of comfort, a scorn of delights, and a life of laborious days, resulting in so much advantage to the whole world (for there can scarcely be a habitable region to which comfortable cotton goods of English make have not by this time found their welcome way), that at length the benefactor, whose memory we cherish as pious with a gratitude beyond that of colleges for their long roll of beneficent donors, would be left in peace to enjoy the fruit of his exertions, and to continue them without let or hindrance. But no; a great patent is a great temptation to infringement by that too considerable portion of mankind which joins to a large covetousness an equally large unscrupulousness, which thinks that any means are justified that bring them the promise of great gain in the end. His servants, when they had thoroughly learned the business, were bribed away from his service, and in this way a knowledge of his machinery and inventions was obtained. From that time his machines were being continually copied and used by piratical rivals, who attempted to screen themselves by some slight alteration in the construction, or even in the name of the machine!

At length, in 1781, Arkwright instituted actions against Colonel Mordaunt, and eight other manufacturers, for infringing his patent. In the first trial, that against Mordaunt, the whole weight of the Lancashire cotton-spinners was exerted to shake the validity of the patent. It is clear that no doubt was then entertained by the formidable body of his opponents as to the originality of Arkwright's invention, for during this trial they did not venture to question it; they would gladly have done so, had they had any opportunity of making this doubtful. The contention was based on the alleged insufficiency of the specification of the patent; this was declared by the court to be obscure and indistinct, and the patent to be therefore invalid. On this failure, the cases against the remaining manufacturers were withdrawn: and shortly afterwards Arkwright, who at that time regarded the adverse decision as final, published a statement giving the story of his inventions and of the difficulties by which his labours had been beset. This was his celebrated *Case*. Its object was to demonstrate that even if his specification was imperfect, yet he really was the man who had invented the water-frame and other machines, to the incalculable advantage of the nation; and it was his intention to follow it up by an application to Parliament similar to that of Watt's in 1775, for a guarantee to him of the patent right of which he had been deprived in a court of law; this intention he did not, however, pursue further.

During the next few years he was able to get what seemed to be important evidence of scientific men on the sufficiency of his specification, and accordingly felt in a position in 1785 again to bring an action for infringement, as a proof that on second thoughts he did not yet see the necessity of relinquishing his patent rights. The case Arkwright *v.* Nightingale was heard in February, 1785, and was successful, the specification being declared by Lord Loughborough, the presiding judge, to be in his opinion adequate. In this conflict of decisions, the matter was, in June 1785, brought by writ of *scire facias* before the Court of King's Bench, to have the validity of the patent finally settled. Here, for the first time and unexpectedly, Arkwright's claim to the invention was disputed. A Lancashire man named Highs, who had in 1770 constructed a fairly successful double jenny to work fifty-six spindles, was now put forward as having invented the spinning-frame. The mechanic Kay was said to have been originally employed by Highs, and afterwards to have communicated to Arkwright the principles of the construction of the machine, which was by him appropriated, not invented. No rebutting evidence was at hand, nor could be conjured up on the spur of the moment: Arkwright could invent machines, he left it to his opponents to invent evidence. The antecedent improbability that Highs' claim would, for the first time, be put forward at this late day if it were substantial or just, does not seem to have impressed Mr. Justice Buller, who declared against the patent. Later on in the same year, when the required evidence could be obtained, application for a renewal of the trial was refused on the ground that, apart from Highs' claim, the verdict was sufficiently sustained by the vagueness of the specification. During the course of this trial, it appeared that thirty thousand people were employed in establishments set up in defiance of the patent, and that near £30,000 had been expended upon these factories.* It is now, under the light of later investigations, abundantly clear that the pretensions of Highs could have had no stronger foundation than

* E. Baines: "History of the Cotton Manufacture of Great Britain."

possibly a belief that roller-spinning was practicable, coupled with attempts, crude, irrational, unsustained, and futile, to render it so. Let him now be dismissed; he hoped to win renown merely by snatching it from the hands of a victorious rival, after his own struggles had proved vain, but he fails even to win the respect which would have been his due if his honest attempts had been followed by an honest acknowledgment of failure.

With regard to the second patent, it appears that the many constituent parts of it, while it was assuming shape in the inventor's factory—his great experimental workshop,—were exposed to espionage and petty piracy. Mr. Baines, in his "History of the Cotton Manufacture," says, "Most of these improvements are to be ascribed to Arkwright, and he showed his usual talent and judgment in combination, by putting all the improvements together, and producing a complete machine, so admirably adapted for the purpose that it has not been improved upon till the present day." It was this complicated system of machinery that had been found so difficult to describe with satisfactory explicitness; any outstanding obscurity in the specification Arkwright himself admitted he had allowed to remain, not as a fraud on his countrymen, for his inventions were open to the inspection of a large band of skilled and trained workmen, but rather that the advantage of his patent might be reserved as much as possible for his own countrymen, and not be at once seized by foreigners. He had better have simply, and with no ulterior purpose, given a fair and full account of his inventions; the manufacturers of England did not thank him for his kind intentions; they were the rather minded to profit by his omission as much as they could, which was far more than he had contemplated, and this even though he should go to the wall. Absolute straightforwardness would have suited his purpose better, and he would have had the validity of his patent confirmed beyond dispute.

In spite of its early and late opposition to the spinning-frame and its inventor, Manchester soon received the chief blessing from the hands of the much needed *deus ex machina*, whose advent had there met with the most obstinate resistance. The first cotton-mill in Manchester was erected on Shude Hill in 1780; it belonged to Messrs. Arkwright, Simpson, & Whitenburgh, and was one of the many similar speculations into which our enterprising inventor ventured. Under his fostering care the most successful cotton-spinning was carried on, and for years he fixed the price of cotton yarn in this country; in this way, patent or no patent, he was able to amass considerable wealth, though he had occasionally to suffer from the burning of a mill by purblind artisans, or from other like inconveniences.

Arkwright used horse-power in his first Nottingham Mill, and it was on account of the expense of this that he removed to Cromford, where water-power was available, and where his yarn was in consequence called water-twist. In the Shude Hill

Mill he used a hydraulic wheel, furnished with water by a single-stroke atmospheric steam-engine; he had already tried the application of steam by one of Newcomen's engines, but these were so imperfect as to lead to their speedy rejection. The first to employ one of Boulton and Watt's engines were Messrs. Robinson in 1785, in their mill at Popplewick, in Nottinghamshire; and their example was quickly and most profitably followed by Arkwright and others. So great was the effect of these improvements in the manufacture of cotton that, whereas the imports of cotton wool averaged less than 5,000,000 lbs. per annum in the five years from 1771 to 1775, they rose to an average of more than 25,000,000 per annum in the five years ending with 1790; they are probably now some fifty times what they were a century since. In 1781 Great Britain commenced the exportation of cotton goods, showing that at this time the manufacture of these fabrics was expanding more rapidly than the home demand for them. This marvellously rapid growth was associated with a stability equally as marvellous: hitherto manufactures had sprung up, and, after brief success, languished and died; they now took deeper and firmer root, and assumed the permanence which is ever a feature of the greatest benefactions.

We cannot but notice how in that busy inventive period the labours of one intent and active mind were made subservient to those of another. Well was it for the cotton industry that the newly introduced "fire-engine" of Watt was available for application in the new power-looms; well, too, for Boulton and Watt that the uses of their engine should thus be multiplied.

In relinquishing his trade in hair and wigs Arkwright had confidence in his own powers, and something of that discernment that flashed straight into the heart of things; he there and then trusted himself to that tide in his affairs which led to fortune. The returns of his venture enriched the world, and brought to him also abundance of wealth. He acquired such a position in Derbyshire that he was in 1786 appointed to the dignity of High Sheriff, and in the same year he was knighted by King George III., on the occasion of presenting an address of congratulation to his Majesty after the attempt on his life by Margaret Nicholson.

Sir Richard Arkwright lived but a few years longer; he died at Cromford, in the year 1792. He is described as having been from his youth athletic and strong, but from the date of his settling in Cromford he had been much subject to asthma, and this malady became finally complicated with others; and so, having accomplished a grander life's work in the domains of peace than has been effected in the battle-fields of strife, he passed.

Of his personal habits we find little to add. That the tree was good is sure from the fruits. For years he was constantly intent on the problem which he had set before him, and on its many ramifications as they suggested themselves to him: this thoughtful intentness, with an accompanying clear-mindedness and perseverance, and a strong will that was powerful to impress others, these are the qualities that made a Richard Arkwright for us. This intentness made his sleep light, and at the first break in his morning slumbers he would be up and at work; in spending time—that wealth which is given to every man who comes into the world—he was severely economical. Mr. Baines, who claims to have received his information from a reliable private source, tells us that when Arkwright was more than fifty years he felt the disadvantage of his deficient education so much that he encroached upon his sleep in order to gain an hour every day for English Grammar, and another hour for writing and orthography. Not many years after his second marriage, he is said to have separated from his wife, "because she, convinced that he would starve his family by scheming when he should have been shaving, broke some of his experimental models of machinery."

The concerns in which he was engaged or interested were very numerous. He often took shares in the mills erected by those who purchased from him his patent machines, and thus made of them a double source of profit. In many of his undertakings he was so much master of the situation that, in one way or other, he was a gainer whether they failed or no. In his speculative schemes he was ambitious and dauntless, a casual observer would have said, to the verge of recklessness. He had the fullest enthusiasm about the success and the importance of his machines, and spoke of them with an extravagance by no means shared by his friends. He was not, however, in danger of dreaming great enterprises his life through without rising to action; he not only said, "This is the thing to do," but found the "cause and will and strength and means to do't." In the fulfilment of his purpose he was "so direct, so sternly undivertible of aim," that success was from the beginning half assured. His life gives us an illustration of the welcome theory that he serves his own purpose best who does most for the good of the world: but we must confess that Arkwright was as fully alive to his own interests as to those of the world, and was as fully bent upon furthering them; in him we look in vain for the disinterestedness that endears self-sacrifice to us. We cannot, however, but be glad that he was wise enough in his own day to make sure of a substantial reward, which, after all, was more to his mind than any amount of endearment to posterity. Coarse, rough, unpleasing he is said to have been throughout his life, but all this ill is buried with him, and for us there remains only the fruit of his extraordinarily ardent, enterprising, and persevering disposition.

CHAPTER V.

SAMUEL CROMPTON, THE INVENTOR OF THE MULE.

THE history of Samuel Crompton is not that of success in the world; his invention prospered, but he did not share its prosperity. He was, indeed, in circumstances almost needy for the greater part of his life. Others, whose story furnishes amusement and instruction hand in hand, have made their mechanical achievements stepping-stones to a well-merited worldly success; it was their ambition to rise from humble beginnings and take a more important position in their country; they not only sought out knowledge of witty inventions, but they kept a hand upon their own discoveries, and exacted some dues, adequate or inadequate, from those who were anxious to profit thereby; and, verily, they were worthy of any reward which thus fell to them. It is too much for the world to expect that those who are, in things commercial, its greatest benefactors should remain in want, unhonoured and unknown. Whatever the energy of a Watt, a Stephenson, or an Arkwright may secure for them by their inventions, it is certain that their free gift to contemporaries and the inheritance left to posterity incalculably outweigh it all; we receive far more than we give, and the balance of the bargain remains vastly in our favour. We do not grudge them the wealth of golden coin that resulted from their partial and temporary control of their own useful inventions, when they have toiled so successfully to "work the welfare of the nations."

We now, however, turn to a man who, in ability and steadfastness of purpose, in the wit to invent an aim and the perseverance to attain it, was scarcely inferior to many of the more prosperous and illustrious members of the brotherhood of inventors. He had not, however, the worldly wisdom which was necessary in order to reap for himself a fair share in the abundant fruits of his labours. If this were a fault, if this is held by shrewder men to be a grievous fault, at any rate grievously he answered it. For not only did Crompton fail to put hands on the wealth which he disclosed, and which proved far to exceed any dreams in which he had ventured to indulge, but he even failed to secure for himself the advantage which he had considered to be the natural outcome of his toil and careful thought, the advantage of using his little invention in peace. He probably, in his secluded life at Hall-i'-the-wood, near Bolton, knew nothing about the ways the great world had devised, by means of which a man of his ability might make sure of some portion of the riches with which his genius endowed the world: he only knew that Hargreave's jenny, with which he had been accustomed to spin from the time when he was sixteen years old, seemed to him capable of improvement, so as to be used not merely as a multiplying wheel, but as a machine for spinning better and stronger yarn; and in his quiet steady way he contrived and re-contrived, constructed and modified and developed his own machine during five years from the time that he was twenty-one years of age. He wanted to improve the spinning machinery, not in order that he might sell the use of it to others, but that he might enjoy some moderate profit by the use of the machinery himself. Even thus his hopes were modest, and his ambition did not go beyond operations on a small scale, suited to his own garret and to a poor man's purse. It seemed hard that this should have been refused him by a greedy world. His invention was, however, too fertile of good to be hidden away in a garret even during the lifetime of the inventor; the world could not suffer such a postponement of a benefit within its reach; and the inventor had to pay the price of his ignorance—to see on all hands capitalists ploughing and reaping in his fields, and gathering treasure which he was scarcely permitted to touch. Later he found some good friends in Mr. Kennedy and Mr. Lee, of Manchester. It is for his sake to be regretted that they did not know and befriend him earlier. If friends had been found willing not only to profit by his inventions, but also to recognize the just claims of the inventor, they would have suggested to him at once the necessity of securing his own rights, rights of whose validity he was unaware, and which he would not have known how to secure. But the fifty gentlemen who first inspected his machine, at a subscription of one guinea each, were bent upon making the most of a good thing for themselves, more than upon helping a poor man in his need, however great a genius should be burning within him, and however great the benefits he might be conferring upon them.

Samuel Crompton was born on the 3rd of December, 1753, at Firwood, in Lancashire, where his father held a small farm. The leisure hours that were not employed in farming were occupied by carding, spinning, and weaving—the great domestic occupation of those days, which enabled farmers and others to add to their moderate means, and to counteract the occasional evils of bad harvests and hard times, which were experienced and dreaded then as now. He was still an infant when the farmer's family removed to Hall-i'-the-Wood, a cottage in the midst of beautiful scenery near Bolton. His father died soon after this, and he was left to the charge of his mother, a pious woman and practical, whose influence upon her son's character was doubtless one of the elements of his excellence. We are told that it was from these years of maternal care that Crompton acquired the sincere and contemplative turn of mind which were his characteristics throughout life, as they had been hers. There are thousands of Englishmen who owe to a similar cause habits of honesty, of patience, and humanity, that become their permanent companions through life, "a possession for ever," of which none dare make them ashamed. In fact, Samuel Crompton was a typical Englishman of the sort who, if they are without wealth and rank, are not without a manhood of which to be justly proud; who know that "the rank is but the guinea stamp, the man's a man for a' that;" who have been imbued with principles that make them straightforward and honest in their dealings with God and man, and who, if they have a failing, err perhaps in being too serious, or in allowing their seriousness to lie upon them with too heavy a weight in the lighter concerns of life. With Crompton there was all this—with an addition, a spark of genius. His education consisted for the most part in the fact of his living in a well-ordered though humble home, and being impressed by the personal influence of a quiet, earnest mother. The simple nature of the man was a reflex of the simplicity that surrounded his early life, and we may discern a greatness in that strict and frugal country life, very different, it is true, from the greatness which is donned for display, and much more honourable; and suited, too, to the unostentatious greatness that conclusively asserted itself in the quiet worker and thoughtful inventor, Samuel Crompton.

Crompton had no dreams of the possibility of a spinner and weaver becoming a millionaire, be he never so ingenious; but he evidently thought, when he was still a lad, that it would be much to his advantage to make use of the best apparatus he could get for his humble work, whereby he hoped to gain a moderate competence. It was in the year 1764 that Hargreaves invented his spinning-jenny, working in secret, without the aid of any capitalist, with the disadvantage of poverty, and the burden of a family of seven children. Under these circumstances his invention did not at once flash itself upon the attention of the world. We are told, however, that before the year 1768 he had mounted and sold several of his jennies; that was the year in which he had to betake himself to Nottingham as a place of refuge from the attacks of his jealous and infuriated neighbours. Yet the very next year the youth Crompton, being then sixteen years of age, and residing not far from the neighbourhood of the riots, was bold enough to purchase one of these hated and abused machines, and at once learnt to use it. He evidently started off in life equipped with common sense and discernment beyond his neighbours, being one of the first to avail himself of the opportunity placed within reach by the new and much-decried spinning apparatus.

Mr. Kennedy, to whom Crompton was much indebted for assistance and advice, and to whom we are indebted for much of the information we possess about Crompton, says that he was altogether ignorant of Arkwright's machine when he invented his own; if this be so, his genius must have been of a high order. But for the strong evidence to the contrary, we should perhaps feel disposed to agree with Baines, who, in his "History of Cotton Manufacture," throws doubt upon Mr. Kennedy's statement. On the one hand, we have the fact that Arkwright's patent was taken out five years before Crompton began the construction of his machine, that Crompton had shown himself to be neither blind nor deaf to improvements in the production of cotton yarn, and that the same principle of rollers moving with different velocities figured in his and in Arkwright's inventions. On the other hand, his own machine more nearly resembles one of Hargreave's jennies than the water-frame; the rollers used were at first far ruder in form than they would probably have been had he been acquainted with the water-frame; and again, on Mr. Kennedy's authority, there is his own word for it that his own work was quite independent. If he had been aware of Arkwright's work, he might possibly have accepted its result as a final solution of the task which presented itself to his mind, and not have pursued the subject any further himself. He desired to improve the jenny so that he could spin warp-yarn; his object, therefore, was identical with Arkwright's: he started off, however, somewhat differently, and the final issue proved to be more satisfactory. But for the seclusion of his life, he might, like the rest of the cotton-spinning world at this time, especially that part of it that operated on a large scale, have been preoccupied with the recent inventions which were just making their way into general use. By one the production of weft had been largely facilitated, and by the other the production of cotton warp had been rendered possible. What then remained for them to desire? They were sufficiently occupied with the work which these machines put in their way, and were for a while content.

There was, however, one disadvantage in these machines, a deficiency that showed itself when they were put to the test of practice. They were not adapted for producing the finer kinds of yarn. Cotton thread of great tenuity had not strength enough to bear the stress to which it was subjected between the two pairs of rollers of the water-frame, and when being wound at high tension on the bobbins. In consequence the finer fabrics, such as muslins, could not be manufactured by means of yarn from this machinery.

Crompton's cogitative mind hit upon a method that proved more successful. He attempted to secure the same end by starting from the spinning-jenny with which he had been accustomed to work, and in the course of his experiments he was led to make use of the principle of rollers revolving with different velocities. Thus his machine united in itself the principles and the merits of its two predecessors, and was found on trial to be superior to them both, and to spin yarn of the finest qualities and of the requisite strength for weaving cotton goods.

To a student of the history of invention and research there is, after all, nothing impossible, and nothing remarkably unusual, in the two men taking up and developing the same idea independently, to meet the same want or advance the same object. In the present instance, too, it is curious to find that Crompton ascribes the first suggestion of rollers in his machine to the very source which has already been mentioned in the case of Arkwright's invention.

Mr. Baine has appropriately applied to Crompton and his invention, compounded, as it practically was, of the two former inventions, an adaptation of Pope's well-known lines on three distinguished poets. He says—

> "The force of genius could no further go,
> To make a third, he joined the other two."

And the liberty may perhaps be pardoned in consideration of the appropriateness of the modified verses. The machine soon acquired the name of the mule, or mule jenny; its nature and capability were fortunately exalted, not debased, by the hybridism.

Mr. Kennedy gives the following brief statement of the progress of the discovery through its successive stages:—

"Mr. Crompton's first suggestion was to introduce a single pair of rollers, viz., a top and a bottom, which he expected would elongate the rove by pressure, like the process by which metals are drawn out, and which he observed in the wire-drawing for reeds used in the loom. In this he was disappointed, and afterwards adopted a second pair of rollers, the latter pair revolving at a slower speed than the former, and thus producing a draught of one inch to three or four. These rollers were put in motion by means of a wooden shaft with different-sized pulleys, which communicated with the rollers by a band. This was certainly neither more nor less than a modification of Mr. Arkwright's roller-beam; but he often stated to me, that, when he constructed his machine, he knew nothing of Mr. Arkwright's discovery. Indeed, we may infer that he did not, otherwise he would not have gone thus rudely to work; moreover, the small quantity of metals which he employed proves that he could not have been acquainted with Mr. Arkwright's superior rollers and fixtures in iron, and their connection by clockwork. Even the rollers were made of wood, and covered with a piece of sheepskin, having an axis of iron with a little square end on which the pulleys were fixed. Mr. Crompton's rollers were supported upon wooden cheeks or stands. His tops were constructed in much the same way, with something like a mousetrap spring, to keep the rollers in contact. His first machine contained only about twenty or thirty spindles. He finally put dents of brass-reed wire into his under-rollers, and thus obtained a fluted roller. But the great and important invention of Crompton was his spindle-carriage, and the principle of the thread having no strain upon it until it was completed. The carriage with the spindles could, by the movement of the hand and knee, recede just as the rollers delivered out the elongated thread in a soft state, so that it would allow of a considerable stretch before the thread had to encounter the stress of winding on the spindle. This was the corner-stone of the merits of his invention."

Crompton's success, however, soon brought difficulties in its train. His endeavours had been actuated by the desire to be possessed of a more perfect machine, and, when he had attained this object, his modest ambition was "to enjoy his little invention to himself in his garret," and to secure by perseverance in its use a moderate addition to his somewhat scanty earnings. The yarn that he produced was, however, so superior to that supplied by his neighbours, that it was speedily surmised that he must be employing machinery vastly better than theirs. From this time he was constantly persecuted and troubled by the persistent curiosity of visitors from the neighbourhood, anxious to have a glimpse at his machine. If he shut his door they climbed up to his window to watch him at work; he erected a screen to obstruct their view, but he was still put to so much inconvenience by the number of visitors, from whom he perhaps unwisely wished to keep the secret of his invention, instead of taking out a patent, that he was almost reduced to despair. It must be admitted, however, that, apart from other considerations already referred to, there might have been insurmountable difficulties in the way of obtaining a patent. The expense would certainly have been at that time beyond his means, and then the fact of his introducing the very principle of Arkwright's patent would have made the result of an application doubtful, if not a certain failure. In fact, it has been stated that he would not have been allowed to use his mule at all but for the adverse decision as to the validity of Arkwright's patent. Under such circumstances, there was perhaps no course left to Crompton more discreet than to preserve the secret of his invention for his own private use. His own intentions at first, as well as the course to which he was afterwards driven, might possibly be not so much at variance with the dictates of worldly wisdom as some writers have imagined. It may be folly akin to fatuity for an industrious operative to surrender to the comparatively rich, without a fair equivalent, the fruits of his ingenious toils in hopes of requital from the world at large, and the absurdity of such expectations may well be contrasted with the sound sense and self-respecting energy of Arkwright, who knew how to look after his own interests; but Crompton, when he could keep his secret for his own private purposes no longer, had perhaps no other choice open to him than either to surrender his invention as a free gift to the world, with which he had no opportunity of coming to terms; or to take the extreme measure of destroying it, a suggestion which actually occurred to him in his perplexity, and which he fortunately and worthily refused to countenance. In a letter to a friend he wrote: "In regard to the mule, the date of its being first completed was in the year 1779: at the end of the following year I was under the necessity of making it public, or destroying it, as it was not in my power to keep it and work it; and to destroy it was too painful a task, having been four and a half years at least, wherein every moment of time and power of mind, as well as expense, which my other employment would permit, were devoted to this one end—the having good yarn to weave; so that to destroy it I could not." We do not find that he mentions the possibility or the hope of obtaining a patent. This refers, then, to the end of the year 1780; in the next year the first trial took place in the matter of the validity of Arkwright's patent; from that time the mule gained in popularity, but it was not so perfected and made public as to come into general use till about the year 1786.

In order to make his machine public, Crompton adopted the suggestion of a manufacturer who went to him and persuaded him that it would be a lucrative thing to disclose his invention to the trade, who would subscribe liberally on his behalf. Accordingly he showed the mule to some fifty manufacturers, who promised to pay one guinea each for the privilege of inspecting it. From this time the invention was out of Crompton's hands; it passed to those who knew how to avail themselves to the full of the advantages which it put in their way.

Meantime, Crompton's distress at having to give to, rather than share with, others the fruits of his four and a half years' labour must have been considerably aggravated when he was compelled to regard these fifty guineas as the only tangible reward of the devotion of every moment of time and power of mind, for so long a period, to the successful compassing of a great and useful end. It was with great difficulty that he could collect even this promised amount; he had to travel many miles with his subscription list, and some refused to pay although he showed them their signature.

These repulses drove him back to solitary toil. He perceived that his only course was to set to work in a humble way with his machine; and by means of great frugality he at length, by the year 1802, succeeded in saving enough to establish a modest manufactory, toiling on steadily and in poverty far away in the wake of wealthier competitors, who were too busily bent on their own success to think of taking in tow the humble benefactor to whom they were indebted for the very possibility of their own rapid progress. His friends, Mr. Kennedy and Mr. Lee, of Manchester, now set on foot a subscription for him, to enable him to increase the small manufactory he had been able to start at Bolton. They obtained £500 for this object; at the same time they prevailed upon him to have his portrait painted by Allingham. This portrait, which has been engraved,* shows him thoughtful, gentle, and possessed

* Baine's "History of the Cotton Manufacture," p. 203.

apparently of a refinement not generally looked for amongst the pupils in life's rougher schools, a man whose struggles had been intellectual and carried on in seclusion from the madding crowd's more ignoble strife.

His other occupations and amusements were not many, but having commenced life by some years of close mental concentration he became habitually busy in some quiet way or other. At Bolton he erected many looms suited to the fancy-work of that town; and, to beguile his own leisure, he constructed for himself an organ, an outward and visible sign of the harmony that reigned within. He had been trained in a frugal school, and the customs of the youth became the confirmed habits of the man; careful as he thus was in all that he undertook, he so managed his slender means that the irksomeness of poverty was always kept at a distance.

After some years, when the mule had done good work and had become popular, it occurred to him to obtain an estimate of the number of machines on his principle that were in use. With this object he visited all the cotton districts of England, Scotland, and Ireland, and discovered that in the year 1812 there were between four and five millions of spindles at work upon his mule principle. He regarded this fact as constituting a claim for some national return to the author of an improvement which had been so quickly and so widely adopted, and he laid the result of his inquiries before Mr. Lee, with the suggestion that an application should be made to Parliament for a grant, in recognition of his merits and services. The suggestion met with Mr. Lee's hearty approval and support, and a memorial was drawn up by Mr. George Duckworth, of Manchester, who, with other manufacturers, concurred in giving a warm support to the application. Crompton himself, with a mind conscious of what was due to a public benefactor, went up to London with the memorial, and earnestly stated his case and urged his claims upon the members for the county of Lancashire, confident that so good a cause needed for its success neither the blustering excitement of a loud discontent, nor the pitiable complainings of a wounded vanity, but merely a calm statement that should first of all win for it careful consideration from the representatives of those who had benefited so largely from his labours. Mr. Perceval, shortly before his assassination, promised to interest himself in favour of the memorial, and accordingly a bill was brought in, and passed, for a grant of £5000 in full, free of all charges.

The rest of his story is soon told. With the help of this grant, Crompton hoped to establish his sons in some business, and he fixed upon that of bleaching. Unfortunately his sons had not the experience necessary to enable them to profit by their father's generosity; they were also involved in a dispute with their landlord, which resulted in a long and troublesome lawsuit: in consequence of these and other difficulties incident to the time, this venture soon left not a wrack behind ; the sons dispersed, and Crompton and his daughter were left in poverty. It must have been to him a melancholy and humiliating fact that, on account of this, some of his friends had again, in the year 1824, to get up a subscription for him ; with the funds then collected they purchased for him an annuity of sixty guineas a year. The amount raised for this purpose was collected in small sums, from one to ten pounds, some of which were contributed by Swiss and French spinners who had learnt the value of his invention, and who pitied his misfortunes. He only lived to enjoy his small annuity for two years. He died on the 26th of January, 1827, leaving his daughter, who had been his affectionate companion and housekeeper, in poverty.

There is a melancholy shade drawing in over the the history of a man of genuine worth and of real mechanical genius, when it has to terminate as Crompton's does. We can pity him for his want of worldly success, but we cannot find in him the fault that calls for blame ; he was "a man more sinned against than sinning ;" he deserved better of the world than he obtained.

CHAPTER VI.

HENRY MAUDSLEY.

THE story of James Watt has sufficiently shown that the success of inventions which require accurate workmanship and exact finish is dependent on the powers of the workshop as well as on the genius of the inventor. His own steam-engine was long delayed in construction, because it needed a more perfect execution of its parts than had been necessary in previous engines. The workshop is rarely much ahead of the work it has to do, and a sudden advance in the quality of the work required called for an advance, as rapid as might be, in the quality of that which was turned out. So striking were the advantages offered by the steam-engine, that the call to the mechanic was an imperative one. It was worth while making Watt's new fire-engine, though at enormous cost, on account of the great economy and efficiency of its working. A workman's accuracy and dexterity were sure of meeting with appreciation and reward, and the attainment of greater skill was in this way encouraged. At the best, however, the requisite excellence of work, with the appliances which the mechanic then possessed, would have been so rare, and the price of the most reliable labour so high, as to act as a serious check upon the general introduction of the steam-engine for all the purposes to which it is now applied, even if Smeaton's gloomy prophecies were not more closely fulfilled. The steam-engine had been perfected so as to promise unprecedented efficiency and economy, it now remained to invent machinery for constructing the parts of the steam-engine with economy and accuracy more than could be expected when everything depended upon the rare skill of superior workmen.

The inventors who fitted up the workshop with new apparatus suited to the new demand are comparatively little known; but in their character they were as worthy of study and admiration; and by their work they contributed as much to the possibility of constructing the new modern machines, as the inventors of those machines themselves. Some of them were worthy to be ranked as the equals of those more renowned heroes of mechanical science whose names are associated with the engines and machines that are directly employed to work the will of all who wish to employ them, to convey them with magical rapidity from place to place, to furnish them with raiment to wear and food to eat, and to bring knowledge and circulate thought in the cheap broad-sheets of a popular press. The inventions designed for the retirement of the workshop are hidden from the ken of the world, but they achieve great results in unostentatious secrecy, and render possible those striking mechanical triumphs which more readily catch the eye and excite the wonder of the most superficial observer. Had not the thoughtful labours of Watt been supplemented by the masterly improvements with which Maudsley refitted the workshop, the steam-engine would have remained a grand idea but partially realized. Both of these inventors were first-rate workmen, who delighted in the excellency of their workmanship. A thorough acquaintance with their craft was the foundation on which both alike built: the one, to use his art for the sake of improving the steam-engine ; the other, to improve his art for the sake of a wider use of modern engines. It was with Maudsley that there originated the great modern advance in tool-making which has gone on hand in hand with the other more noticeable mechanical progress of the century, supporting and supported. Mr. William Fairbairn has stated that when he first became acquainted with mechanical engineering there were none of the self-acting tools which now enable work to be done with increased rapidity and greater perfection, everything was executed by hand: there was the old-fashioned, ill-constructed lathe, innocent of any marked improvement for centuries. There were a few drills and boring machines, utterly inadequate to the performance of the tasks then for the first time required. It was not then understood that a machine was the best worker that could be employed, if only it could be constructed of the requisite strength, and worked by some power with sufficient certainty and regularity. The part of an artisan is frequently to copy some fixed design; and we now know well that it is best to substitute, in work that requires a union of great accuracy and great strength, the reliable action of machinery for the uncertain workmanship—less perfect and more costly—of the human hand. Now, any little mechanical process that is constantly repeated is relegated to some simple piece of machinery specially designed for it. Half a century ago men could go on shaping pens by laborious handiwork year after year, and the man who first contrived a machine for stamping and making them was so far ahead of the times, and yet so much needed by the times, that he speedily laid the foundation of one of the largest, as it certainly was one of the best employed, of modern mercantile fortunes.

Henry Maudsley was the son of a disabled soldier, who resided in Woolwich after his discharge, and found employment in the carpenter's shop at the Arsenal. The boy was born in the year 1771, in circumstances of outward disadvantage which do not usually suggest a career of general usefulness. We are too apt to regard the range of man's achievements as circumscribed by a humble lot, forgetting that the mass of men fall short of what they might attain, and that in every rank in life there are found some who stand out from amongst their fellows, and approximate to attainments and successes that are open to all. If a prize is not reached, it would not be a sound inference that it is not within reach. A man's lot does not forbid him

> "The applause of listening senates to command,
> The threats of pain and ruin to despise,
> To scatter plenty o'er a smiling land,
> And read his history in a nation's eyes ;"

it may oppose some hindrances, but he may grasp the skirts of happy chance, and breast the blows of circumstance, and win more by his victory than was lost by his birth's invidious bar. Lives of great and successful men invariably demonstrate that a man's capability for greatness depends more on what is within than on what is around him.

When Henry Maudsley was twelve years old some work was given to him in the Arsenal, and after two years he was put to assist in the carpenters' shop where his father was at work. He had, however, a strong natural bent for metal work, and whenever he could escape from the carpenters' shop he was enjoying himself at some work with the blacksmiths near at hand. When it was found that he could not be kept out of the smithy, and that he worked there with an enthusiasm which gave promise that he would become a good workman, he was removed there, being then about fifteen years of age. He soon took his place as one of the best hands in the workshop. Not by dull diligence and heavy perseverance did he arrive at the excellence which distinguished him from his fellows; by diligence and perseverance it is true, but actuated and sustained by a vivid interest in all that he undertook. Any specially difficult piece of forging was for him a specially attractive occupation; and there were some favourite little jobs, tests of superior skill, which he was particularly fond of turning out, to the admiration of his companions.

At that time Joseph Bramah was endeavouring to carry out his inventions for the improvement of locks. Those hitherto in use had been of the simplest contrivance and could be picked without difficulty. He attempted to make the lock a puzzle so perplexing as to baffle the ingenuity of the would-be thief. In this he fully succeeded. For a long time he placed a notice in his shop in Piccadilly offering a reward of £200 to any one who should succeed in picking his patent lock. All efforts were in vain until the Great Exhibition of 1851, when at length Mr. Hobbs, the American lock-maker whose name is now so well known, triumphed over the difficulties which it presented. Bramah's lock was a delicate contrivance of springs, sliders, and levers, and it could only be serviceable if the parts were made with extreme accuracy, an accuracy that could only rarely be obtained by the best workmen. It, however, promised to supply a great want, and the next problem was how to make the locks in sufficient number to meet the demand.

In this perplexity Bramah applied to all the chief mechanicians who might be likely to assist him. In his search for the best mechanical skill, he heard of young Maudsley, of the Woolwich Arsenal, whose fame had already extended to his fellow-craftsmen of London. Bramah sent for him, and was delighted to find that he had some valuable suggestions to make for manufacturing the new and intricate locks, although he was but a youth of eighteen. Bramah offered him employment in his own workshop; this he left Woolwich to accept. There was some question whether he could take his place amongst the rest of the workmen there, for he had not served the usual seven years' apprenticeship, and seemed too young to have become an experienced workman otherwise. He saw the difficulty, and proposed to make good his footing in the shop by making a worn-out vice-bench, which caught his eye, as good as new by six o'clock that evening. His offer was accepted, he set to work with a will, and by the appointed time he had, in the opinion of master and men, turned out a first-rate job, and thrown all the other benches in the shop into the shade.

He was soon acknowledged to be the best hand in the shop, as he had been at Woolwich, and his excellence, coupled with his hearty cheerfulness, made him the favourite of all.

He was specially useful in designing tools to make the parts of the new lock, which, but for this well-applied inventiveness on his part, must have remained a curiosity instead of making its way into general use. He deserves to share the honour of introducing improved locks. The very lock which, after more than sixty years, resisted the efforts of Mr. Hobbs for sixteen days, was his identical handiwork.

After a short time he was appointed head-foreman of the works, to the satisfaction of every one. He also set up house, and married Sarah Tindel, his master's pretty housemaid, who made him a good wife.

Bramah was a man of fertile invention. After the locks, he turned his attention to the hydraulic press. This, too, would have remained a good idea frustrated by practical difficulties, but for the assistance rendered by Maudsley. It was he who invented the self-tightening collar in which the piston-rod could work without allowing the water to escape from the cylinder. He thus made it possible for the hydraulic press, which is the simplest and most serviceable packing-press, to act. By his contrivance the enormous pressure of the water, which was the very source and cause of the difficulty, was turned from an enemy into a servant, and itself made the collar water-tight, as needed.

A most useful piece of apparatus, which Maudsley designed for Bramah's workshop, was the slide-rest, for attaching to lathes ; a contrivance with which his name is usually identified, and one whose importance cannot easily be over-rated. His other tools were generally designed to be of service in the manufacture of some particular part of a particular machine; but the slide-rest is of service in constructing perhaps every machine; it is a tool that no workshop can be without. Mr. James Nasmyth says that the first slide-rest was the beginning of those mechanical triumphs which give to the days in which we live so much of their distinguishing character.

In the old-fashioned lathe the workman applied the cutting tool at a great expenditure of strength, and with inevitable variations of strength and of attention which made it impossible to copy a design or turn out duplicates with exactness. It was perhaps the necessity of making the same parts in large numbers and with great accuracy that turned Maudsley's thoughts to the improvement of the lathe by the introduction of the slide-rest. The principle of his invention was, that, while the work revolved, the cutter, firmly gripped by the rest, travelled slowly with the rest in a direction parallel to the axis of the work. All that the workman had to do, when once the tool was fixed, was to turn the screw handle, when the cutting would proceed from one end of the material to the other with a regularity which is beyond the reach of human labour. By a further improvement the rest is made to slide automatically in the required manner whilst the work is revolving.

After having remained eight years with Bramah, and failing to get higher wages than thirty shillings a week, Maudsley determined to start a shop of his own. In 1797 he opened a business in Wells

Street, Oxford Street. Here he fitted up his shop with the best and most accurate tools, and brought his slide-rest to greater perfection. His aim was to make tools as much as possible self-acting and self-regulating; and in so doing he prepared the way for the ready performance of any work that might be required of the workshop, and made possible the execution, without delay, of the myriad inventions whose realization has characterized this century.

Having aided Bramah, he next rendered signal service to another great inventor, Sir Marc Isambard Brunel, and in this his slide-rest stood him in good stead. It was in the year 1800 that Brunel sought his assistance in constructing the block-making machinery which he had invented, but which his inexperience in practical mechanics prevented his carrying out alone. In Maudsley he found the ingenuity, the skill, and the interest in the work which were necessary for its success.

The blocks used in ships' rigging for the raising and lowering of sails and yards, although simple enough in appearance, were by no means easily made. It was necessary that they should be made to work as smoothly as possible, for the difficulty of raising or lowering a sail might in an emergency decide the fate of a vessel; and this end required greater care than we are apt to imagine. An immense number of these blocks was wanted, as many as fourteen hundred being required for a 74-gun ship. The work was one eminently suited for machinery, for large numbers of the same kind were wanted, and the only difference was one of size. Maudsley constructed working models of the machinery according to Brunel's design; these were submitted to the Lords of the Admiralty in 1801; the execution of the machinery itself was at once authorized, and it was completed by Maudsley in about six years. In 1808 the manufacture of the blocks by the new process was commenced. From that time to this the machinery has been in use in the Portsmouth Dockyard, and is still working as well as ever. There are forty-four distinct machines for making a ship's block, and each machine was so well and carefully constructed, that it will bear comparison with the best and most modern productions in this age of rapid advance in tool-making.

A man who achieves a piece of work of this magnitude with so great success is sure to find work enough put into his hands. Maudsley's business increased rapidly, and he opened a larger concern in Westminster Road, Lambeth; at the same time he took a partner, and the new firm of Maudsley, Field, & Co. began its course. He continued to improve the working appliances of his craft, and lived to see that the impetus he had given in this direction set in motion a deal of auxiliary inventiveness amongst others. His workshop was one of the most excellent and well-fitted in the country, and all kinds of difficult mechanical work was entrusted to it, flour and saw-mills, mint machinery, and steam-engines.

In 1807 Maudsley had taken out a patent for the simplification of the action of the steam-engine: this was the invention of the direct-acting engine, in which the reciprocatory motion of the piston-rod is converted directly into the rotatory motion of the crank. Later he directed his attention to marine engines, in which compactness, the fruit of neatness in design, is most essential; the form which he adopted became the type of its class, and the work which he commenced has been continued by the firm with eminent success. They have fitted the White Star line of mail-steamers, and other vessels, with four-cylinder compound marine engines, which work to about 5000 horse-power, and "exhibit a remarkable economy in the consumption of fuel; presenting, in fact, an admirable practical illustration of the excellence of the system now adopted in powerful steamships." * The effect of the improvements introduced into the workshop was rapid and great; although they took place behind the scenes, the advantages that followed were soon enjoyed by the general public. One of the new machines was designed to punch iron plates—a simple enough task, it might be thought, with or without a machine; the effect of this was that the cost of preparing plates for ships' tanks to receive the rivets was reduced from seven shillings a tank to ninepence.

Maudsley's name is also associated with the earliest improvements in screw-cutting apparatus.

* Goodeve, "Text-book of the Steam-engine."

In the cutting of screws uniformity throughout the length of the work is of the utmost importance, and very perfect machinery is now used for the purpose. The contrivances of Maudsley were followed up and brought to perfection by his pupils, Joseph Clement and Joseph Whitworth.

Henry Maudsley's contributions to mechanical progress were not limited to the tools which he contrived, and which could be applied with marvellous success to work of the newest and most difficult sort. He did even more than this in training men, capable of carrying on what he had begun by designing still more powerful apparatus to meet the requirements of advancing invention. Invention outside the shop could come to little without invention within its walls, and the invention of new tool-machines could not proceed without new demands from without, *altera alterius auxilio eget.* Maudsley's workmen and pupils had constantly before their eyes a standing example of success founded upon thoroughness of work; they were trained in the best practical school, in one where carelessness or inexactness of finish was not tolerated or excused. Having obtained a practical acquaintance with the processes and machinery in use, they were able to appreciate and to take a vivid interest in the changes that were frequently adopted, not for the sake of mere experiment, but to fit the apparatus to some new end, and give it facility in performing new or better work. Maudsley made his machines to perform their functions with undeviating certainty; those who laboured under him, too, were taught to aim at the same excellence in all that their hands turned out: but in them he had material that offered possibilities beyond that of inanimate metal, and he adapted it to higher purposes; their habit of working neatly and accurately was but a stepping-stone to their inventing wisely.

None but the good workman who thoroughly understands what he is about can know the requirements of his own machines and tools, or be trusted to bring them to greater perfection; he must first work carefully with what he has, and then his workmanlike habits will fit him to undertake the improvement of his apparatus. Maudsley's workshop naturally attracted the best mechanics, and it became a first-rate school for mechanical engineers: amongst his pupils were Clement, Whitworth, Nasmyth, and Roberts, besides others of less distinction. To have sent these men out into the world was a prouder boast than to have achieved his own mechanical triumphs. For a succession of such workers the nation is content, at present, to trust to the good offices of similar schools, as they may chance to arise in different parts of the country. It is hard to avoid the conclusion that if there were a permanent institution, with the stability of our universities, for training mechanical engineers, and that if in it were associated the best workmen and the chief masters of their craft, in its practice and its theory, the advantage to the nation and the world would be even greater. The education afforded by a training in such a school, whether partial or complete, would be more generally useful than much of purely literary education which is carried to a corresponding stage.

Nothing in Maudsley's work was too trifling to be interesting to him, and a small point that excited his attention made a lasting impression, and was recalled for reconsideration, and for renewed application of the lesson he had learnt from it, on every available occasion. Thus he found that tools with sharp internal angles were liable to split at those angles, and he accordingly laid it down as a principle in all his work that the metal in such places should be well rounded off. He used to hold up his hand and point out the beautiful way in which the hollow between two fingers was rounded off by the great Artificer, and to the way in which branches grow from their trees, as illustrations of the principle he had adopted.

Having had considerable experience of men when they were at their best—that is, when they were exerting themselves at work,—he acquired a shrewd facility in discerning character; and after an interview with a stranger, he used to fix the standard of the man according to a novel method of his own. The ideal perfection of manhood was set down as 100°, and there were regular gradations down to the zero of absolute worthlessness. He would sometimes say to Nasmyth, after some applicant for advice had left him, "Jem, I think that man may be set down at 45°, but he might be *worked up to* 60°;" recognizing that a man may be greatly improved by training in a good school.

Maudsley suffered considerable annoyance at times, owing to his frequent neglect to patent the inventions which he was unceasingly making. He was sometimes threatened with actions by persons who had had the unscrupulousness to patent his own inventions.

Those who had the privilege of knowing Henry Maudsley recognized in him "the beau ideal of an honest, upright, straightforward, hard-working, intelligent Englishman;" others, too, may see in the thoroughness of his work an outward and visible sign of the distinguishing honesty of his character, and a proof that he did with a will whatsoever his hand found to do; and in his many beautiful inventions, sufficient evidence of a vigorous and well-trained intellect. He always hit out a clear thought of what he wanted to do, and of how he proposed to attain his end; the same may be said of all great and successful inventors. Besides, he was one of the brightest and most cheerful of men, and continued through life a favourite with all his associates and workmen. He died on the 14th of February, 1831, having caught a cold on his way home from a visit to France. He lies in Woolwich parish churchyard; over his remains is a cast-iron tomb, made after a design of his own.

CHAPTER VII.

JOSEPH CLEMENT.

LIKE to Maudsley in aims, abilities, and success, was his younger fellow-labourer, Joseph Clement, a native of Westmoreland, born at Great Ashby in the year 1779. His father was a hand-loom weaver in humble circumstances, for hand-loom weaving had seen its best days, and was already yielding ground to the victorious rival methods in which machinery was employed. But, poverty notwithstanding, he was a most interested student of various branches of natural history, and occasionally occupied himself with a little amateur mechanics, working on a lathe of his own construction. He pursued these occupations of his leisure solely for the pleasure they afforded him, and turned them to account in this way only. He knew intuitively, what many better-taught men seem almost unable to learn, that the first essential of happiness is that the faculties shall be exercised upon something. He made his life worth living, poor though he was, by contriving a pure and simple enjoyment for his spare hours, which could be indulged in without expense, and remembered without remorse, and which made him a more capable and better-informed man. He may to the majority be more of an example, if less of a hero, than his son. It was his example which helped to consolidate the character of his son.

When Joseph Clement was still a boy, and before he had learnt in the village school more than a trifling amount of reading, writing, and arithmetic, he was taken by his father to assist at the hand-loom. His father was, however, mindful of his own experience of hand-loom weaving, and early determined to find some better employment for the lad. He therefore made a thatcher and slater of him, at which calling he worked until he was some twenty-three years of age. There is no record of the way in which Clement did his thatching and slating; the monotonous work, requiring no particular excellence in the workman, and developing no worthy skill by practice, was not much to his liking. He had seen how his father made things with his lathe, and he also took to similar pursuits for his own amusement. Whenever he could, he would go to his friend the blacksmith's, and spend hours with him in the smithy, so that he acquired skill in handling the tools, and could do any ordinary smith's work expertly, and with an honest pride. His father had been content to fill up his free time with his chosen pursuits, and he strongly advised his son to keep to his slating for a livelihood, as "something sure," and not to be drawn away from it by his liking for smith's work, which would serve him very well for a recreation, or when his other work was slack. But Joseph Clement soon became so expert a workman that there was clear promise of something as sure, and better for him, as a mechanic. His interest, too, had received an additional stimulus from the perusal of some books on mechanics, which a cousin of his had brought with him on returning from London. He began to make tools and apparatus for himself, amongst which was a good lathe, a great improvement upon his father's; showing, as many have shown before him, that the true workman is never long at a loss for the implements of his art. With his lathe he turned fifes and flutes, on which he learnt to play, for he had a taste for music, which he did not suffer to lie dormant. He took an interest in his father's entomological studies, and constructed for him a microscope after the descriptions of the instrument which he could find; then he showed an appreciation of the wonders of astronomy by making a reflecting telescope. This son of a poor weaver had, in fact, tastes so varied and refined that they would have been an enviable possession to any man, even in those more favoured ranks of life which they are generally supposed to adorn; where, however, they perhaps abound, not because of their greater natural vigour, but because of a more careful tending. In the apparatus of the workshop, too, he designed sundry improvements, and was already on the track of those improvements in screw-cutting, which, followed home, gave him his chief claim to distinction in after life.

At length he left the unpromising slating work, and obtained employment at making power-looms in the neighbouring town of Kirby Stephen, where he sold his telescope to his employer for £12. He was afterwards engaged by Foster & Son, of Carlisle, at similar work; and it is evident that they gauged their man rightly when, on his leaving them to go to Glasgow in 1807, they wrote that he had conducted himself, whilst in their employment, with great sobriety and industry. To be diligent in business is the first condition of success, whether it be before kings, or in the face of the people, and is inconsistent with an indulgence in the frivolities and dissipations which keep most men on the low level of mediocrity, even when their faculties, properly developed, might raise them to excellence.

At Glasgow he found work as a turner. He went there fearlessly, determined to make his own way where workmen the best and the most numerous would be found to compete with him for work and for the rewards of superiority. He went there also with the determination, or with that better un-selfconscious tendency, to make the best of the advantages a large place would offer him to improve his workmanship, and to enlarge his powers. He had not been there long when he made an opportunity to learn drawing. Peter Nicholson, an ingenious and distinguished writer on carpentry, happened to call at the shop where Clement was at work, for the sake of making a drawing of a power-loom. Clement saw the drawing when it was finished, and requested, as a favour, the loan of it that he might copy it. His request was granted, and he stayed up night after night in his humble lodging, and worked steadily by the light of candles, which his means would scarcely allow him to buy, until he had finished his copy. He then took it to Nicholson, who accepted it as his own drawing, until Clement told him it was only the copy. Nicholson looked at him, and said, "Young man, *you'll do!*" The sequel of this approval of the tyro by the expert was that Nicholson undertook to give Clement lessons in drawing gratuitously, and the learner soon became a first-rate draughtsman. This new acquirement was of great value to him as a mechanic, but he made it serve other purposes by following it up in a different direction, for he added to his store of innocent pleasures that of landscape drawing.

His next engagement was at Aberdeen, where he earned good wages as a high-class workman, in designing and making power-looms for Messrs. Leys, Masson, & Co. He continued to make advances in the course he had struck out for himself, improving his workmanship, his tools, and his mind; for this last he attended a course of lectures in natural philosophy at the Marischal College. By the year 1813 he had managed to save about

£100, with which he decided to go to London, and try what fortune his good right hand and his sound common sense might bring him there.

His capacities as a workman, coupled with the rare ability to draw, at once obtained work for him at Galloway's, one of the largest mechanical workshops in London. Here he began by astonishing his fellow-workmen by putting into first-rate order the inferior tools that were given to him, and by showing a mastery of his work such as they had not before witnessed. When pay-day came at the end of the week he received one guinea, much less than he had been earning at Aberdeen, and much less than his deserts, as every man in the shop was ready to admit. No advance was, however, made on this, and at last an old workman advised Clement to ask for work from Bramah, who always wanted the cleverest and the most expert men about him to carry out his numerous new ideas. Bramah gave him a short trial, and saw that he had got hold of a good and true man; he accordingly offered to give him double of Galloway's wages for three months, and placed him in charge of the tools of his shop. When the time was up he was so satisfied that he gave him a handsome present, and said, "If I had secured your services five years since, I should now have been a richer man by many thousands of pounds." An agreement was then entered into, by which Clement undertook the office of chief draughtsman and superintendent of the Pimlico Works, at a salary of three guineas a week, with an advance of four shillings a week in each successive year of the engagement.

Bramah had already lost one good workman by refusing to advance his wages; perhaps, in the years that had elapsed since Maudsley left him, he had learnt that it was wise to be more liberal to men who could in five years make him "a richer man by many thousands of pounds." The arrangement made with Clement was eminently satisfactory on both sides. His own business prospered, for Clement gave himself up to making it successful, and, with clear head and steady hand, fitted up the shop with approved apparatus, and enlarged its capability by many clever contrivances of his own.

When Bramah died, his sons took over the business, and, being jealous of the important position which Clement occupied in the concern, they managed to get rid of him. Jealousy blinded them to their best interests, but their jealousy was united with ignorance of the rarity and value of skilled and intelligent labour. Clement was taken on, without delay, at Maudsley & Field's, and entered into the construction of the marine engines of that firm with his natural steadiness and insight into mechanical designs, and proved of great service to them. He did not, however, stay with them long, for, when he had saved enough money to open a small workshop of his own, he determined to do so, and accordingly started in business on his own account in the year 1817. By this time he had earned a great reputation as a most reliable workman, to whom the most accurate work might be safely entrusted; but, in addition, he had so cultivated his taste for mechanical drawing that he stood unrivalled as a draughtsman, and all the most difficult drawings of elaborate machinery in the "Transactions of the Society of Arts" were handed over to him, and were executed with a quite unprecedented precision. He invented mechanical contrivances for the accurate drawing of ellipses and for a straight-line motion, to aid him in this work; and for this latter invention he received the gold medal of the Society in the year 1818.

By this time experience had shown him that, if he persevered at any improvement which he desired to effect, he was capable of attaining his object. He thus acquired increased confidence in his own powers, and found the best of all encouragement to follow up to a successful issue the numerous suggestions which occurred to him. He concentrated a powerful mind upon the proposed object, and rarely failed to accomplish the purpose he had in view. The improvements which he from this time onward introduced into the apparatus of his workshop were many and were of incalculable value. Their worth was from the first duly recognized by those who were competent to understand their merits; but his inventions were not of a sort that could appeal to the general public with the directness and force of those which are connected with the names of Watt and Stephenson. They could not flash a sudden surprise into the minds of men, as the locomotive did, but their usefulness to mankind cannot be reckoned the less on that account; and if it is ignorance that unfits men to appreciate the benefits conferred upon them by these quiet but most serviceable workers, the diffusion of more knowledge is all that is needed to make the names of Maudsley, Clement, and their fellow-labourers honoured universally amongst those heroes whose victories in peaceful pursuits have been not less important than those which, won on the battlefield, have earned for their heroes the title to greatness.

We have seen how Maudsley invented the slide-rest; Clement devoted himself for a long time to making further improvements in this machine. In 1818 he designed a slide-rest specially adapted for screw-cutting, and working automatically, that is, adjusting itself in the right position without the constant supervision of the workman. In 1827 the Society of Arts awarded him the gold Isis medal for his improvements in the turning lathe, which rendered it much more manageable, and overcame some defects which had previously interfered with the perfection of the work turned by it. For instance, it is clear that if the revolving shaft, to which the work to be turned is attached, rotate with uniform velocity, the cutting tool will move over more of the material in one minute to begin with, when the diameter of the work is considerable, than afterwards when the diameter has already been diminished by the action of the cutter. The different velocities with which the cutting tool moved over the surface of the material constituted a practical inconvenience, and indeed damaged the cutter and interfered with the proper performance of the work. There had before been contrivances of wheels for altering the velocity of the mandrill, or revolving shank, at will, with a view to controlling this imperfection; but Clement finally remedied the defect by his invention of self-acting machinery which made the material pass under the cutter with the same velocity during the whole of the process of turning. Thus the mandrill would revolve with a varying velocity under the control of the new machinery, but means were devised by which the workmen could, if desired, restore the uniform motion of the mandrill.

Another improvement, for which Clement received the silver medal of the Society of Arts in 1828, was the self-adjusting double-driving centre-chuck. It was one of the embarrassments of common experience that, in turning a long cylinder, the pressure of the cutter upon the material shifted the centre slightly and gradually, so that the axis at one end of the completed cylinder was not coincident with that at the other end. The work was fixed on a centre, and also fixed to a driver at a short distance from the centre, which, when it revolved, forced the material to revolve with it. The pressure of the cutter made the actual centre of the work, after some time, move from the original centre in the direction of the point of attachment of the driver. To overcome this difficulty, Clement invented his two-armed driver, the two arms being equidistant from the centre; or the double-driving centre-chuck, as it is called; and this proved effectual, and made it possible to turn metal with all the accuracy which was desired.

To Clement is due the introduction of a practice now universally adopted among screw-makers, and of great importance. It used to be the custom for different screw-makers to have their own practice with regard to the pitch of the screws they made; there was no general rule followed by all. As a consequence, when a piece of work containing screws needed repairs, the engineer to whom it was entrusted could not use the thread which had served hitherto, but had to prepare the material to receive his own screws, at much expenditure of labour and money. Clement adopted a fixed rule, making the number of threads to the inch dependent upon the size of the screw, and succeeded in obtaining the adherence of other mechanical engineers to the same uniform practice.

We next come to an unpatented but very important invention, that of the planing machine for metal work. The fact that no model of this was made, but the machine was constructed directly from the original working drawings, shows how clearly Clement saw through the whole of a complex mechanical invention, and also how perfect a draughtsman he had become. The planing machine was more nearly a modification of the turning lathe than of the carpenter's plane. The cutter was fixed, or only had the same kind of lateral motion that the cutter in the lathe possessed; and the material to be planed moved backwards and forwards beneath the cutter, with the most exact precision of movement. Great care was needed, as well as great ingenuity, in order to secure a motion of the material that would present the different parts of it to the cutter with the regularity which had been attained in the lathe; without this, true planing would not be insured. The metal travelled on rollers, and means had to be taken to prevent vibration in its mass, especially when its motion was changed from one direction to the opposite. Clement himself said of the machine, "If you were to put a paper shaving under one of the rollers it would stop all the rest." Large as the machine was, it was as accurately constructed as the most delicate and intricate piece of mechanism. This does not exhaust all the inventions which Clement contrived for the aid of workers in metal; they are, however, his chief contributions to mechanical art, and this record, brief and incomplete as it is, will show that he well deserves a place amongst our great benefactors of this century.

The fame which Clement had won as an expert and intelligent workman decided Mr. Babbage to engage him for the construction of his difference engine, when he received the first Government grant on account of it in 1823. Clement saw that he was accepting a task that would require special appliances, and specially skilled labour: he proceeded to invent tools for the construction of the parts of the machine, and to train a set of workmen for the use of the tools. In a work of so great intricacy the exact workmanship of each of the myriad parts was of the utmost importance. The undertaking was very laborious and required great ingenuity; it was in consequence costly, and its progress was but slow. At length there arose complaints about the enormous expenses incurred. The public somehow got the notion that the money was finding its way into Babbage's pocket, than which nothing could be more unfounded. His own contributions to the expenses of construction were scarcely less than the sums granted by Government. The public, Government, and Babbage, all, however, looked upon the charges as excessive, and Babbage did not hesitate to ascribe the misfortunes of his machine to the exorbitant charges of the engineer. On the other hand, Clement regarded himself as worse paid for this than for any other of his professional work. At length, in 1833, Clement withdrew from the work, taking away with him his workmen and the special tools he had designed for and used upon the machine. The construction was never again resumed. The part already completed was as great a triumph of mechanical skill as of inventive power, and was as much to the credit of Clement as of Babbage.

There are one or two other instances in which those who employed Clement did not think their labourer worthy of the hire at which he rated his services. Brunel, of the Great Western Railway, called upon him, and, showing him the steam whistle in use on the line, asked him if he could supply anything better. Clement looked at the whistle, and, characterizing it as "tallow-chandler's work," at once undertook to construct something more effective. He designed a tool specially for the purpose, and sent one of his new whistles to Brunel, who was delighted with it—it could be heard miles off—and ordered a hundred of them. He was surprised at finding a bill of £40 sent in for them, and objected that this was six times as much as the ordinary price; "Yes," said Clement, "but my whistle is more than six times as good." The matter was referred to an arbitrator, who decided in favour of Clement.

On another occasion an American ordered a screw, as accurate as could be made; Clement took him at his word, and sent a most perfect piece of workmanship, and a bill for £20. This, too, was referred to arbitrators, and with the same result.

His early taste for the finer arts evinced itself once more before his death, by his constructing a large organ at a cost of some two thousand pounds and of much labour. In all his work, as well as in this, there was an interest in his art which in his case raised it above the labour of a calling. Enjoying as we do the fruits of his labours, we can scarce forbear to praise his zealous toil and to admire his well-won success.

He died in 1844, having made himself one of the worthiest of England's sons; not elbowing his way to a good position by the little arts which are the poor resource of little men, but advancing by honest work, by force of the characteristics which distinguish great men.

CHAPTER VIII.

JAMES NASMYTH.

JAMES NASMYTH comes of an old Scotch family, whose records narrate the doings of many remarkable men. True, he was not born to a high position in the social world; but this is a small thing in comparison with the privilege of birth into a gifted family, with a rich mental and moral heritage, "the pith o' sense, and pride o' worth," which qualify the inheritor to take his position in the upper ranks of the intellectual world. James Nasmyth's is an ancestry of exceptional worth; the guinea's stamp of which the poet speaks was not always there, but there was no doubt of the genuine metal; that was apparent to all, though it might sometimes be in a rough state.

The name, to begin with, is peculiar; and to it a curious story is attached. In the times of James III. of Scotland, the Douglas was a formidable subject, and open rebellion sometimes took head in him, culminating at length in his tragic end. On one such occasion the Douglas party won a partial success on the field, and the royal troops were dispersed; amongst these was an ancestor of James Nasmyth. He took refuge in a neighbouring smithy, and with apron and hammer disguised himself as an assistant of the smith. Shortly, however, the victorious party came in pursuit, and burst into the smithy in search of any concealed foe. Just then the inexperienced make-believe of a workman brought his hammer down with so much force or so little skill that the handle broke clean in two. The pursuers at once rushed upon him, exclaiming, "You're Nae Smyth;" and it was with difficulty that he and the true smith, the one armed with a dagger wrenched from the hand of an opponent, the other wielding a hammer, his own tried and trusted weapon, succeeded in turning the king's enemies out of doors. At this moment royal reinforcements arrived, and the Douglas experienced a severe defeat.

The name Naesmyth thenceforward clung to the soldier who had thus distinguished himself, and for the service rendered to the royal cause he received from the king a considerable grant of lands. His armorial bearings consisted of a hand dexter holding a dagger between two broken hammer shafts, with the motto, "Non arte sed marte." It is a descendant of this same Naesmyth that first showed the world how to wield a hammer as it had never been wielded before, and, no longer despising the smith's craft, has won from it a world-wide glory.

Hence he has appropriately altered the position of one letter in his ancestral motto, reversing its meaning, and making it read, "Non marte sed arte."

In the days of the Covenanters the branch of the family from which James Nasmyth is descended lost their estates, and had to begin at the bottom of the ladder again. Michael Nasmyth, who was born in 1652, and lived in the Grassmarket, Edinburgh, was a builder and architect; his occupation became hereditary in the family. He is said to have acquired a high reputation for the excellence of his masonry and woodwork.

The grandfather of James Nasmyth, also named Michael, was, like his forebears, a man who did thoroughly and with brains all that he undertook; and his grandson, in his autobiography, dwells with affectionate pride on the highly finished character of his work, and the care and attention he devoted to it; nothing merely moderate would do. Already the spirit of the true artist was in the family. He aimed at giving to each part that perfection which is the secret of the pleasure derived from works of art. This characteristic he handed on to his descendants, as their talent to be multiplied for the service of the world. They have shown themselves worthy of the trust.

This Michael Nasmyth left two sons; the second, Alexander, was the artist whom Sir David Wilkie eulogized as the founder of the Landscape Painting School of Scotland. Of Alexander's sons one was Patrick Nasmyth, a distinguished artist; the youngest was James Nasmyth, the inventor of the steam-hammer.

Alexander Nasmyth was not only an artist, he was also a man of great mechanical ability, an inventor of no mean merit, and an architect with a considerable practice. He was an intimate friend of the poet Burns, of whom he painted the only authentic portrait. Another of his friends was Mr. Miller, of Dalswinton, an ingenious man and a large shareholder in the Carron ironworks, to which he gave a wide celebrity by the invention of the carronade gun ; but still more worthy of notice as the first actually to apply steam-power to propel ships. The first steam-boat was built by him ; it was a small pleasure-boat constructed on the twin principle, which has after a long time been revived for the passage between Calais and Dover. It ran its first trip on the waters of the Dalswinton Lake, and carried amongst its few select passengers Robert Burns and Alexander Nasmyth.

Whatever engaged the attention of the intellectual world of the time excited the interest of Alexander Nasmyth. He associated with the most prominent men of science in Edinburgh, and with them talked over theories new and old. But his chief friendships were naturally among artists, of whom there was then at Edinburgh a distinguished group, including David Wilkie, Francis Grant, Clarkson Stansfield, and Henry Raeburn. He was, indeed, one of the most enlightened and refined figures in Edinburgh society.

James Nasmyth often accompanied his father when he took his accustomed walk with some friend, probing scientific problems, discussing art theories, or enthusiastically admiring the grandeur and the beauty lavished round them in nature. These excursions had their influence on the boy; they raised him to a high level of thought whilst he was still young, and encouraged a refinement of feeling that early became the "habit of his life." The same friends, too, frequently dropped in and enlivened the evenings at home by their pleasant company. The Nasmyth family was on these occasions always well occupied with modelling or planning, or in some other way with pencil or needle; and when friends came in to have a "crack," their work went on without interruption, but did not prevent them from taking a lively part in the conversation. At length supper would be announced, and the visitors would share the homely fare; the hospitality was of the heartiest,—it was generous without ostentation, and abundant without extravagance.

James Nasmyth was the youngest son of the family. He was born on August 19, 1808, at his father's house, No. 47, York Place, Edinburgh. His happy childhood was passed in an old-fashioned Scotch home, where there was a genuine simplicity and heartiness about life, true kindliness of feeling and dealing between the various members of the family, and between these and the servants who were almost recognized as part of the family. His father, who was incessantly busy, was a pattern of well-directed industry, which must have produced its influence on his children. James, at any rate, confirmed his mother's opinion that he was "a very noticin' bairn;" for when he was only about four years old he pulled one of his father's visitors by the coat-tail, and informed him confidentially, "My papa's a kevie fellae!"

Besides his studio, Alexander Nasmyth had a mechanical workshop, fitted up with tools in great variety, and containing many ingenious contrivances of his own invention. Here James Nasmyth began to handle tools at a very early age; here he found his first technical school. His amusements often consisted of shaping and making things with hammer, chisel, or file; and he learnt to construct deftly at an age when children are often content with destroying clumsily the handiwork of others.

It was this home influence which endowed with a special interest to him the workshops of sundry workers in metal, who lived in the valley on the northern side of Calton Hill. From the smiths of all sorts who worked there, James Nasmyth's intelligent and quick observance acquired many a suggestion in manual dexterity; and some of their manipulative devices were made thoroughly his own by repeated practice in his father's workshop at home. His boyhood was in this respect not unlike that of James Watt, of whom his father's workmen were accustomed to say that he had gotten a fortune at his fingers' ends. He became so clever in his handiwork that he was called a little

Jack-of-all-trades. This was before he went to school.

From his first school, where he learnt to read English with ease, he was removed on account of the brutality of the master, who on one occasion violently assaulted him for ignorance of the exact significance of the preterpluperfect tense, and, seizing him by the ears, beat his head against the wall until the poor child fell stunned to the floor. It was more than a week before he recovered from the effects of this cruelty.

From the year 1817 he attended the Edinburgh High School for three years. He, perhaps, gained something from submitting to the discipline of a large school, but he made very little progress in the classical studies to which he was there introduced. The truth is they were from the first distasteful to him, and they were not put before him in an attractive way. Amongst the boys he soon acquired popularity by a supply of beautiful tops which he turned with his father's foot-lathe, by the excellent kites he made, and by the brass cannon, the fruit of his mechanical skill, which were in great request. There were, too, other pursuits that he loved. Anything with the savour of antiquity about it, such as old buildings with their quaint ornament, and old coins with their beautiful designs, was full of interest to him. He often took a long way round on his way to or from his school, in order to pass through the narrow streets of old Edinburgh, and enjoy the examples of old styles of architecture with which they were filled. He learnt something, too, about the history of these strange-looking ancient houses which fascinated him so powerfully. He also made a collection of old coins, and it was his delight to make accurate drawings of these for an illustrated catalogue which he kept with his cabinet of coins. One day Sir Walter Scott entered the house to see Alexander Nasmyth, by no means an unusual circumstance, and noticed James at work copying a fine bronze coin of Augustus. He came forward and saw how carefully and with what zeal the boy was executing the drawing, and, pulling a beautiful silver coin of Mary Queen of Scots out of his pocket, gave it to his young brother antiquarian, as he called him, to add to his collection.

Modern inventions succeed one another like the links of a golden chain forged by men of godlike skill for our support, and, indeed, for our elevation. The cloak of an Elijah often falls upon the shoulders of an Elisha. We like to think that Milton as a boy might have trod in the veritable footsteps of Shakespeare. So, too, it is interesting to know that James Nasmyth had the pleasure of looking upon his great forerunner in mechanical invention, James Watt. It was in the year 1817, when the inventor of the modern steam-engine was on a visit to Edinburgh, that he called to see Alexander Nasmyth; and James, whose ambitions even then tended towards mechanical excellence, saw with admiration the man who had made the pursuit of it so glorious. The sight of Watt stimulated his hopes and his efforts.

Nasmyth left the High School when he was about twelve years old. The classical education they had attempted with little success to give to him there was not at all suited to his bent. He asked for food, and they gave him a nauseous poison. What is food for one mind may be poison to another. There are eminent men who would have been practically lost to usefulness and fame, if they had entered a workshop and attempted to fight with stubborn matter after the manner of a Watt or a Stephenson. Nasmyth had no dislike for study in itself. Such studies as he did delight in he continued to pursue by attending private classes. If the mental exercises in which he was drilled were not merely memory work, but appealed to his natural tastes, as was the case with Euclid and mechanical philosophy, he manifested an ardent passion for them, and followed them up with untiring zeal.

He had the benefit of his father's most excellent instruction in drawing, under which, and by constant practice, he learnt to represent graphically the relative proportions, the lights and shades of any miscellaneous group of objects placed before him. This art, useful and valuable to any one, was specially so to him as a preparation for the work to which he afterwards devoted himself. He varied his occupations by systematic work in his father's workshop, at the lathe, the furnace, or the bench;

and he continued the study of chemistry, which he had begun before he left the High School, with one of his schoolfellows, whose father, a merchant of Leith, had a special genius for practical chemistry, and was heartily glad to encourage his son and his young friend in their incipient enthusiasm for the same study.

Nasmyth records with evident satisfaction that he made his own tools and his own chemical apparatus; and it was by doing everything connected with his work thus thoroughly and whereever possible by his own unaided efforts, that he acquired that complete mastery of every part which prevented him from feeling at a loss when mechanical difficulties had to be overcome. That was a good principle he adopted, that he should become independent in his work as a step towards acquiring independence by his work. He was fully provided in himself for every emergency, and had not to rely on the advice or assistance of others.

There was one other contribution to his education at this time. It was found in the walks with his father and his father's friends round about Edinburgh, from whose conversations he derived his "mental culture of the best kind."

Truly this is a picture of versatile industry which it would be difficult to parallel in the life of any other boy between the ages of twelve and fifteen!

When he was fifteen years of age he enlarged his experience by a visit to Stirling in the company of his father, who had a commission to paint a picture of the castle. He enjoyed this little journey thoroughly. Stirling, with its castle well worthy of note for its architecture and its wood carving, was full of interest; the walk past the waterfalls that enlivened the glen of the Ochils was charming: but more fascinating even than these were the strange sights seen at the Devon Ironworks. Here they saw the great steam-engine that worked the blast furnace, and they waited to see the furnace opened at the proper time, and the molten white-hot metal flow out into the sand troughs prepared for it on the floor of the foundry, where it hardened into the pig-iron of commerce. Another similar treat was in store for him. He made the acquaintance of Robert Bald, a mining engineer of considerable reputation. With him he often went when business journeys called him away from Edinburgh. On one such occasion they went over the Carron Ironworks, where great men had wrought mighty works; where Roebuck, Watt, and Miller of Dalswinton had made a reputation; where the separate condenser, the carronade gun, and the application of steam to water-carriage were first realized.

By the time he was seventeen years of age his practical knowledge was so matured, and his skill so reliable, that he began to apply them with success to the construction of engines and machines for his own purposes. Amongst the first of these was a small steam-engine, for grinding the colours for his father's work as an artist. He then made sectional models of the condensing steam-engine for use in the lecture-room. He sold several of these, one being purchased by Professor Leslie, of the Edinburgh University, for use in his lectures on natural philosophy. With the profits of these sales he provided himself with tickets to attend the courses of lectures delivered by the Professors of the University; but Professor Leslie allowed him to attend the natural philosophy classes without a fee, as a recognition of his services. Aided by these lectures, James Nasmyth made great advances; he never attended one of them without meaning business. These were supplemented by other lectures, as excellent and thorough, given in connection with the Edinburgh School of Art. This institution was founded in 1821, with the object of giving to working men and mechanics scientific instruction, as systematic as that given in the lecture-rooms of the University. The lecturers were men of the highest ability, who took pains to give every possible assistance to their classes. The classes were filled with eager students, who made substantial progress in their studies. The education was sought and imparted for its own sake; it had not its end, in any sense, in an examination to be passed. This School of Art has been looked upon as the forerunner of mechanics' institutes; but it did not aim at exciting a few hours' wonder at scientific discoveries; its object was to train the intellect, and to give a satisfactory education. This work has not, as a rule, been characteristic of mechanics' institutes; possibly because there have been wanting in most places qualified teachers willing to take charge of the classes. The want has, however, been felt to be a real one; and it is now met by the series of university lectures in populous centres, whose initiation is due to the exertions of Professor James Stuart. In connection with this, qualified lecturers are set apart to carry on the required work. It is of such a system, rather than of mechanics' institutes, that the Edinburgh School of Art was the true prototype. James Nasmyth attended the lectures of the School of Art regularly from 1821 to 1826, and found in them a source of knowledge more to his taste than the elementary classics of his boyhood.

When all his pursuits were followed with so much ardour, it is difficult to say which was the favourite. The one, however, to which he gave every odd interval of his time, and for which he often stayed up late at night in his own room when he was supposed to have gone to bed, was the construction of models and other metal work. To this all other pursuits were subservient. For this he turned his bedroom into a brass foundry, making careful preparations to deaden the sound of ramming the sand into the moulds, so that the rest of the house should not be disturbed, and that his father, who had forbidden this night work, might not prevent it. Here, and in his father's work-room, he made nearly the whole of his steam-engine models.

When his own foundry apparatus was not equal to some large piece of work in hand, he was able to carry it over to the foundry of his friend George Douglass, who gave him every assistance and convenience for completing it. In return for this kindness, Nasmyth set to work to make a large direct-acting, high-pressure-steam-engine, which he presented to Douglass to drive the machinery of his workshop. This was a very valuable gift, and Douglass turned it to good account; it led him on to fortune.

Nasmyth's earliest attempts at invention were made about this time. He devised an expansometer, or instrument for measuring the amount of expansion of solids for different increments of temperature. Sir David Brewster at once recognized the merits of the invention, and was glad to publish an account of it in the *Edinburgh Philosophical Journal*, of which he was editor.

He also constructed for the Scottish Society of Arts a road steam-carriage, after the plan of a model which he had constructed and exhibited to the Society. This steam-carriage ran for nearly three months on the Queensferry Road, near Edinburgh, but it was clear that it was not destined to be a commercial success, whatever might be its merits as a mechanical solution of a great problem. It was necessary to solve the mechanical problem, and at the same time to make it profitable for the world to adopt the solution. The first condition makes it a theoretical success; the second is required in order that it should be a practical success. James Nasmyth was at that time so fully occupied with his studies and engineering pursuits requisite to fit him to become a practical engineer, that he did not follow up the subject any further. The Society of Arts presented him with the steam-carriage he had made for them. He broke it up, and sold the two small engines belonging to it for a sum sufficient to cover all the expenses incurred.

He seized every opportunity of examining different specimens of steam-engines in the various breweries, distilleries, and other large establishments where they had a use. Examination led to comparison, and this gave him a high opinion of the excellent engines supplied by the Carmichaels, of Dundee. He found that this firm was foremost in introducing the new machine tools which were then effecting a revolution in mechanical work, not only making that easy which before was hard, but also making that cheap which before was dear. He also found that some of the leading men at the Carmichaels' had received their training at Maudsley's celebrated workshop in London. It was to these causes that the excellence of their engines was to be attributed. It was therefore to Maudsley's shops that Nasmyth now desired above all things to go, that he might enjoy advantages in technical training such as could be obtained nowhere else in the kingdom.

There were difficulties in the way. The most usual way of obtaining his desired object in a workshop like Maudsley's would have been to have entered as a pupil apprentice, but this would have required a larger premium than his father could have afforded. He was, however, informed that the firm of Maudsley and Field declined any longer to receive pupil apprentices on any terms; they had tried them, and had not found them industrious or useful; they therefore did not wish to have them on the premises. These difficulties were not enough to damp James Nasmyth's hopes. He determined to win an entrance on the strength of his merits as a working engineer, though the way was doubly barred. The first proof of his merit, which he prepared to take up to London, consisted of a beautiful model of a high-pressure engine, the work entirely of his own hands. Knowing full well the value of his attainments in mechanical drawing, he added several carefully executed specimens of draughtsmanship, and some examples of his sketches of machinery in perspective. When these were all ready he and his father started for London, which they reached after a four days' coasting voyage.

Alexander Nasmyth had been introduced to Maudsley some few years before. He promptly called upon him, introduced his son to him, and explained the object of their visit to London. Maudsley received them kindly, but at once frankly told them that he and his partner had made up their minds not to take pupil apprentices again at any premium. He may, at the same time, have thought that a good mechanical workman was not likely to come out of an artist's family. He saw, however, that they would be interested in seeing his workshop, and offered to conduct them over it. This was a great pleasure to them, and the more James Nasmyth saw of the cleanliness, order, and precision of all the operations in process, the more he burned to be admitted to a part in carrying them on. As they were passing the steam-engine which worked all the machinery in the shops, the man in charge of it was engaged in wheeling away the ashes from under the boiler furnace. James Nasmyth, turning to Maudsley, exclaimed, "If you would only permit me to do such a job as that in your service, I should consider myself most fortunate!" This outburst of enthusiasm was at any rate proof that the present applicant was a different order of being from other pupil apprentices who had been there before, and Maudsley looked at him and said, "So you are one of that sort, are you?"

James Nasmyth evidently made a favourable impression on Maudsley in the course of this inspection of the works; and he then asked to be allowed to show him the model and the drawings which he had brought up from Edinburgh for the purpose. His request was granted, and the evidence which he had thus worked out in his own favour was enough to prove that he was a workman of the highest ability. Maudsley told him immediately that there was no need to talk of premium or apprenticeship in his case, he would be glad to engage him at once as his personal assistant in his own private workshop. This was in May, 1829.

Nasmyth knew that the object for which he had striven so earnestly and so successfully owed its chief worth to the opportunities it would afford him to attain still greater excellence and the best experience in the work which he had chosen. He felt that, in the position which he now held, all external obstacles to his progress were removed, and that his success in life depended solely on his own exertions. He determined that efforts on his part should not be wanting to make the most of the golden opportunities which he enjoyed. As a matter of fact, he had only to continue true to his former self. The same high qualities which had enabled him to remove the obstacles would enable him to press forward along the cleared road.

He did not at once set to work. Maudsley desired that he should take advantage of his father's presence, for a week, to see in his company the chief objects of interest in London, and to make the acquaintance of his father's friends. He therefore gave him a week's holiday. This time was well spent in seeing the sights that were of special interest to him; he also received a hearty welcome to London from the artists and men of science who had shared Alexander Nasmyth's friendship in Edinburgh. From Henry Brougham he obtained an introduction to Michael Faraday, of the Royal Institution, a privilege which he highly prized, and which was the commencement of a long and friendly intercourse.

This pleasant holiday over, James Nasmyth commenced his duties as Maudsley's private assistant at the beginning of June, 1829. He immediately began to put his resolutions into practice; he was no mere dreamer of fine things. Knowing that his success depended upon his own exertions, and upon his letting no opportunity slip to get the mastery which comes of practice, and the insight into mechanical problems which comes of a large experience, he entered into his work with ardour and enthusiasm. Apart from his fixed determination to make his present privileges a stepping-stone to future success, he took a real interest in the work which occupied him; he enjoyed the work for its own sake. An excellent workman to begin with, he had every opportunity of improvement in his new surroundings. The most delicate and the most complicated work, requiring attentive thought and careful manipulation, was entrusted to him; and he took a pride in turning it out in the best possible way. In the course of this work he had frequently occasion to devise machine tools to ensure accuracy and precision in the construction of similar parts of machines and models. He was in a position to call into play all the inventive powers he possessed. From the very first he was Maudsley's right-hand man; and he, on his part, had the highest admiration for his employer, whose friendship, example, and advice he learnt to value the more the longer he remained with him.

Being an assistant workman and not an apprentice, he at once began to draw a small salary. Maudsley told him at the end of the first week to make arrangements with the cashier for the amount of wages he might consider satisfactory. A man's estimate of the value of his services is often inversely proportional to their real worth. At any rate, Nasmyth, mindful of the great advantages which were now within his grasp after having seemed so splendid and so inaccessible, made up his mind to ask for the least amount which would enable him to live without being any longer a burden on his father. He therefore announced that he would be satisfied with ten shillings a week, which by very careful management was made enough to meet his ordinary expenditure. Of this amount three shillings and sixpence was spent for the rent of his lodgings. He devised an economical cooking-pot, and had it made by a neighbouring tin-smith; in this he allowed his dinner to stew during the day, and when his work was done he came home and enjoyed "a capital dish, such as a very Soyer might envy," at the moderate expense of fourpence halfpenny. A little care in selecting the ingredients of his pot gave him a much cheaper and much more savoury repast than he could have got at a cookhouse. His other arrangements were equally economical, and it was not till his second year in London, when he had an advance to fifteen shillings a week, that he was able to have butter to his bread. His privations were endured with every encouragement and good hope for the future; his life was not embittered with discontent, or vain with regret. When extraordinary expenses arose he had something to fall back upon, for he had saved £20 before he left Edinburgh, and to these savings he was able to add £35 received from the sale of the model steam-engine which he had brought up to show to Maudsley, and which had served its purpose so well.

Nasmyth's workshop life brought him other advantages than practice and technical knowledge. He enjoyed an occasional intercourse with not a few distinguished men whose business or tastes had made them acquainted with Maudsley, and who came to consult him or to talk over matters of common interest. Amongst these were General Sir Samuel Bentham; Mr. Barton, of the Mint; Bryan Donkin, who was associated with Barton and Maudsley in fixing the standard yard; and the sculptor Chantrey. He was also able to find congenial friends with whom to pass his hours of leisure and recreation.

After working for fifteen months he was allowed a month's holiday, whilst Maudsley was absent in Berlin to superintend the erection of machinery for the Royal Mint. It was in the days when George Stephenson's great project for steam locomotion between Liverpool and Manchester was about to be realized. In the trial of locomotives the Rocket had received the prize offered by the Directors, and preparations for opening the railway were nearly complete. Nasmyth determined to go down to see the Rocket, and to be present at the opening of the line. He travelled down by coach to Liverpool, and spent a week there. The line was opened on the 15th of September, 1830. After he had seen the extensive docks on the Mersey and visited some of the chief engineering factories, he set out to walk back to London, taking in on the way all the places and objects within reach that could delight one who was an enthusiastic admirer of the beautiful in nature and art, and of excellence in all kinds of man's handiwork. He saw Manchester with its great factories, including that of Messrs. Sharp, Roberts, & Co., a firm much indebted to Maudsley, for Roberts had worked with him in London, and was one of his most distinguished workmen. He heard here, and in many other places, praises of his master as the pioneer of mechanical improvement, praises which found a prompt echo in his own judgment. He visited the ironworks of Coalbrookdale, the furnaces of the Black Country, the workshops of Birmingham, and, above all, the famous Soho Works, where Watts completed his engines, and whence he was able to supply them to the world. Then, on his walk back to London, through the beautiful midland counties, with their roads bordered by green grass, and their majestic trees, and through old towns full of architectural interest, his thoughts often turned on what he had seen in the great centres of industry which he had visited. Those great factories, with the perfect order and cleanliness that reigned throughout, with their perpetual motion all devoted to the creation of useful and well-shaped things out of mere masses of formless metal, those places where human energy was chiefly concentrated, and where it seemed to be most directly exerted in the service of the world, these had a charm to attract his aspirations and a promise to satisfy his ambition. To be at the head of a well-ordered concern of that sort, turning out every day its tale of finished articles for the world's use, might well seem to him to offer the surest means of making life worth living; and he more than half determined that he would come back there, and there work his way up to the success which others had attained.

Maudsley returned from Berlin a few days after Nasmyth reached London. He, too, had much enjoyed his holiday. Amongst other things, he had seen the Royal Observatory, and came back with the intention of constructing a large telescope for his own use. An instrument of this sort is an object well worthy of a great mechanician's attention; it demands the utmost precision in making its parts, and therefore the most practised skill. Nasmyth suggested that it would be easier to make a reflecting than a refracting telescope, a big mirror of good quality not presenting the same difficulties as a big lens; at the same time he undertook to cast a smaller speculum, according to some ideas which he had previously thought out, in order to exhibit its optical qualities. This and other work was proceeded with as usual, being begun with that intelligent enthusiasm which is not inconsistent with experience, and completed with that success which generally attends the endeavours of masters of their craft. Then came Death, the disturber. After a short illness Maudsley died, in February, 1831.

Nasmyth continued in the service of the firm, the business being carried on by Joshua Field, who had been Maudsley's partner. He, too, was a man from whom Nasmyth found something to learn. In the construction of a machine the whole of its life-history should be borne in mind; it has to be made as easily as possible, it should work as effectively as possible, and it should be capable of being repaired as promptly as possible. For the last purpose the parts should be so arranged that they may be got at without unnecessarily pulling to pieces other parts of the machine. This is a principle which Joshua Field always insisted on; he called it the *get-at-ability* of parts. It may seem simple enough; but no principle which it is necessary to keep in mind in practical work is too simple to be formulated, when this ensures that it shall not be overlooked.

Again, he adopted from Field the habit of keeping a graphic diary of all business consultations on the construction of machines. In these conversations a rapid sketch was often of the greatest service in saving words and in precluding vagueness. Instead of sweeping these sketches into the waste-paper basket at the end of the day, Field thought they were worth preserving for reference, as a record and easy reminder of the conversation. He therefore entered them on successive pages of a note-book, and found them of great value, especially when, as often happened, his business consultations on any one subject were separated by a considerable interval of time. Whatever he noticed in others which might be of assistance to himself in making his own success sure, Nasmyth promptly appropriated.

He remained only a few months in London after the death of Maudsley. As a step towards starting in business on his own account, he returned to Edinburgh, there to make all the machine tools necessary to fit up his workshops. He erected a small temporary workshop close to the foundry of his old friend George Douglass. Here, with the assistance of one labourer to turn the wheel of his lathe, and of a faithful workman, Archibald Torry, whom he engaged at fifteen shillings a week, and whose hearty co-operation was well worth the price, he commenced the manufacture of his own machines and tools. In order to obtain means for this limited undertaking he consented to take a pupil at a premium of £50 for a year's instruction, and he also occasionally took up orders for extraneous work to relieve him from financial difficulties.

When all was ready he went once more to Liverpool and Manchester, to choose the place in which he should commence business. He was received with great kindness by those on whom he called;

they gave him encouragement and promises of assistance. One wealthy ironfounder, who was about to retire from a business in which he had amassed a fortune, was so favourably impressed with Nasmyth's straightforwardness, courage, and ability that he offered him the opportunity of entering the business as his successor. The character of the work was, however, not quite to Nasmyth's liking; it would have given him a fortune quickly, but it would have taken him away from the careful mechanical part of the business, which he particularly loved. He therefore declined the kind offer, and indulged in the hope that there might be even brighter prospects before him in other directions, though the path to their realization might be difficult. He made many other friends in this visit, among whom were the Brothers Grant, of Manchester, wealthy and benevolent merchants, and the originals of the Brothers Cherryble of Dickens.

The result of his investigations was that he decided to settle in Manchester. He took a flat in a large factory, and had all his apparatus removed there. And now the friends who had already given him a helping hand followed up their kindness by sending orders, and James Nasmyth was soon on the highway to success. The work done by him was always so well done that more was sure to follow. He could be relied upon for repairs suddenly needed in the machinery of neighbouring manufacturers. He supplied them with his improved tools, and executed for them the most difficult and important parts of machines they were constructing. He bound himself to them in the safest way, by making it evidently to their interest to employ and support him. He soon became very busy in his factory flat, and won fame by his ingenuity in mechanical devices. His business flowed over into the cellar, to which his forge-work was relegated; and he had at length to obtain some outside assistance for casting work. The time, indeed, was one which gave every chance of success to an industrious and energetic man of Nasmyth's peculiar ability. The success of the Liverpool and Manchester Railway had been followed by the construction of other lines, concentrating in Manchester. This created a new demand for ironwork of various sorts, and a demand which Manchester had the first chance of meeting. This in itself would have directly benefited a venture like Nasmyth's. But there was also an indirect effect. The demand for skilled labour was in excess of the supply; the wages of all workmen were increased, for there were so many employers competing for their services. Also, in order to complete a good order, the employers were sometimes obliged to yield to a demand for a rise in wages. The effect was not altogether good; the men did not work the better for their better wages; they sometimes worked the worse, being able to spend more days in idleness and drunkenness, and sacrificing to a brief indulgence their steadiness and worth as workmen. In this emergency the introduction of self-acting tools, by means of which one man could do the work of many with unprecedented accuracy, was a great gift to men. Nasmyth expresses what employers of labour generally must have felt at the time, when he says, "The machines never got drunk; their hands never shook from excess; they were never absent from their work; they did not strike for wages; they were unfailing in their accuracy and regularity, while producing the most delicate or ponderous portions of mechanical structures." Nasmyth came in for a large share of the business in these machines; for those that he supplied were chiefly self-acting, and of a quality so good that "they were their own best advertisements." His floor became so loaded with heavy machinery that the tenant of the flat below, a glass-cutter, became alarmed for his safety, and not without cause—one day the end of an engine-beam came crashing through his ceiling; and it was clear that those premises would suit a prosperous business like Nasmyth's no longer; he had grown out of them.

He found an admirable site at Patricroft, on the Bridgewater Canal, on the Liverpool side of Manchester. It was bounded, on the one side, by the canal, with a neat stone wharfage; on another side, by the railway; and on the third, by a good road. It was thus provided with facilities for all methods of transit, of material and fuel to a foundry, and of manufactured goods from it. Here the Bridgewater Foundry was built in the year 1836, and the locality soon assumed a different appearance; the rustic solitude became alive with workmen, the leisurely operations of nature gave place to the bustling labours of busy men.

In the neighbouring village of Barton he took a comfortable cottage, surrounded by beautiful rural scenery. One of his sisters came to live with him here. When his day's work was over he would occupy himself with his pencil in sketching choice bits, or would indulge in tranquil thought in the course of a ramble over the fields or along the lanes. In labour such as his there was no degradation; a refinement of manners and of thought lived with it. Ruskin has said that it is only by labour that thought can be made healthy, and only by thought that labour can be made happy. By these means Nasmyth enjoyed healthiness of thought and happiness in toil. He thought about his foundry work, and, besides, he thought beyond it and worked above it; the art to which his father and his brother had devoted themselves also had attractions for him. The science that essayed to conquer all mysteries by rule and line deprived them of no charm in his eyes; its touch the rather endowed them with a new fascination for him.

His intelligent thought about the work upon which he was daily engaged had its natural result in the inventions which we owe to him. The first of these at the Bridgewater Foundry was his safety foundry ladle. The foundry ladle is a sort of large cauldron for carrying the molten metal to the casting moulds, and pouring it into them. The old-fashioned ladle was clumsy and dangerous; it was swung round to the moulds by a crane, and often splashed its contents over upon the workmen; it was then awkwardly tipped up by several men with great difficulty and danger, and emptied into the large moulds. Nasmyth's improvement consisted of an application of screws, so that one man could pour the liquid metal out gently, easily, and safely. He did not patent this invention, but sent drawings of it very generously to the principal founders at home and abroad; it was soon universally adopted. The Society of Arts of Scotland awarded him their large silver medal for this invention.

In order to carry on his extensive business efficiently in all its branches, he found it expedient to take in a partner who could devote himself to the financial part of the work and to the general correspondence, so that he might himself be relieved of this, and be able to give all his attention to superintending the mechanical department. He did not seek a partner for the sake of getting more capital into the concern; he therefore declined many offers from men who saw that the business in his charge was sure to be a safe investment, and who were anxious to become sleeping partners. Of these he fought shy; he wanted assisting thought and energy to be employed in the business, and these he found in Holbrook Gaskell, who remained his partner for sixteen years, only severing the connection then on account of a serious illness.

The difficulties of managing the large concern which had grown up under his care were not altogether mechanical. He had to control a large body of workmen, and to secure the hearty co-operation of all in the undertakings of the firm. His great idea was to be on the watch for special merit, and to encourage and reward it. Thus he got the best work out of his men, for they found that they were serving their own purposes most when they were serving his. Evidence of ability was essential before a man was employed at the Bridgewater Foundry; and superior ability was the only recommendation for promotion, and was sure to find substantial reward. There were sufficient industrious and skilful men in Lancashire to take work under these terms, and with an employer of established success.

But there was an Engineer Mechanics Trades' Union, which considered it their duty to enforce a different principle. They held that none except those who had served a seven years' apprenticeship should be employed as workmen in the trade. Nasmyth's practice made nought of their principle, set up another in triumphant conflict with it. Hence they protested, choosing as their hour of protest one in which a large number of important orders were in hand, when they inferred they would be able to dictate their own terms. Nasmyth had never concerned himself with the question whether his men belonged to the union or not; being satisfied with their skill, he engaged them. But it appeared that about half of the men employed at the foundry were members of the union. A deputation from the society waited on the heads of the firm, and remonstrated with them for employing other than union hands, who alone were, on their authority, legally entitled to the trade. They pointed out that these outsiders were not only allowed to work, but were given the best berths; and this was undoubtedly true when they happened to be the best men. This was contrary to the interests of the less competent but "legally entitled" mediocrities of the union, and added vigour to their protest.

Had there been a legal title such as the union claimed, Nasmyth would evidently have been obliged to yield. But legality cannot be conferred on an illegal title merely by calling it legal. Nasmyth, therefore, would not, under any pressure, give up the principle which he had chosen as the soundest and best in managing his business. He was therefore informed that all members of the union would be withdrawn from his employ. Those who left were sorry enough to leave the good and promising position which they held; but they were obliged to obey the orders of their council. All attempts to supply the vacant places from the neighbourhood were frustrated by the pickets of the union, who prevented the approach of all who desired employment. Advertisements for skilled Scotch workmen were then inserted in the Edinburgh newspapers. These met with a quick response from a sufficient number of men, who took the precaution of sending a deputation to Patricroft to inspect the works and the place. The report being in every way favourable, over sixty able Scotch workmen in the prime of their strength were engaged. They all came together, bringing their wives and families and eight-day clocks. Against them the pickets were of no avail. They set to work at the foundry, and took possession of the comfortable workmen's cottages which had been built by the firm. By their means, in the humorous words of James Nasmyth, the strike was scotched. Thus the triumph of the great principle of free trade in ability was assured.

In the year 1838, whilst on a journey through Yorkshire, he stayed a day or two at the house of a Mr. Hartop, the manager of some ironworks near Barnsley, belonging to Earl Fitzwilliam. Here he met Mr. Hartop's daughter Anne, to whom, after two years, he was married. He refers to this event as the source of his greatest happiness in life. To success and happiness in the work of his hands and in the management of his many workmen, was added happiness above all in the private relations of his life. The world was a bright place in general, but the brightest spot of all was home.

If we think of it, Nasmyth was the man for the time, for the work which was then wanted. After the first railways came others in great numbers, and the demand for steam-engines of the best description was enormous. A firm that could meet this demand was sure to flourish, and of these the firm of Nasmyth and Gaskell proved itself amongst the foremost. The care and intense interest which Nasmyth himself took in constructing and improving machine tools gave them an advantage of which they speedily reaped the fruit. In carrying out orders for railway companies in all parts of the kingdom, the great mechanician was constantly devising some simplification or some extension of his workshop machinery, thus improving the character of the work turned out, as well as diminishing the time and cost of completing it.

The Great Western Company invited the firm to tender for twenty of their ponderous engines, and offered to increase the price of each by £100 beyond the contract price, if at the end of a month they proved thoroughly satisfactory. The firm supplied the engines, and won the promised reward, and also a valuable letter from the directors, expressing their entire satisfaction with the engines, and their willingness to bear testimony to the excellence of their workmanship, when called upon.

This connection with the Great Western Railway is important, because it led to Nasmyth's greatest invention, the celebrated steam-hammer, with which his name is everywhere associated.

This is the story of its invention. The large paddle steam-ship, the *Great Western*, had proved so great a success, that the Great Western Company decided to build another of even larger dimensions, and the machinery was partly constructed for the purpose when a difficulty arose in forging the large wrought-iron shaft for the paddle-wheels. With the hammers in use at the time it was impossible to forge so large a mass of iron; when placed on the anvil it simply gagged the hammer, and gave it no distance to fall; thus the greater the fall that was needed, the less was the fall which could be obtained. There was evidently something wrong about this sort of hammer, whose capabilities were inversely proportional to the requirements of the work in hand. The matter was referred to Nasmyth by the engineer of the Great Western Company, who had taken up the question of the new steam-ship with ardour and with a strong personal interest. Nasmyth, on the very day of the receipt of the engineer's letter, sketched in his scheme-book (a book similar in many respects to the graphic diary which had been kept by his former master, Joshua Field) the first plan of a steam-hammer. This was on the 24th of November, 1839. He communicated the result of his rapid thoughts on the subject to the engineer of the Great Western Railway, who was delighted with the invention, as were also the directors. It afforded their only chance of forging the big shaft which they needed, and it would certainly have been adopted but for the successful application of screw propellers, which received the approval and support of Brunel, and whose adoption enabled them to dispense with the construction of the large shaft which would have been required for paddle-wheels. Nasmyth sent drawings of his invention, with description of its uses, to the chief iron-founders in the kingdom, offering to supply them with the new and most serviceable machine. He received in return many congratulations from iron-masters, but no orders; for it was a time of great depression in the iron trade, and work could scarcely be found to keep the old hammers occupied. From its page in the scheme-book, however, the steam-hammer exhibited its merits to all and any visitors to the Bridgewater Foundry, of whom there were many both English and foreign, who came to see the latest mechanical improvements, and who rarely left without being persuaded to purchase many more machine tools than they had intended. A man's self-recommendation is not generally listened to with excessive respect, but the self-commendation of a working machine or tool is the only sort of praise which is worth accepting, and this was the praise which the visitors to the Bridgewater Foundry could not help hearing from the iron tongues whose eloquence re-echoed throughout the works.

Amongst others there had one day called, when Nasmyth was absent from the works, M. Schneider, proprietor of the great ironworks at Creuzot, in France, accompanied by M. Bourdon, his mechanical manager. When they had seen the various departments at work, they went into Nasmyth's office, and, as an act of courtesy usually shown to distinguished visitors, the scheme-book was shown to them, and the design for a steam-hammer. Of course Nasmyth was informed of their visit, but the inspection of the scheme-book was not mentioned, being a fact of everyday occurrence. In April, 1842, he was requested to inspect the French dockyards and arsenals, and to confer with their directors on possible improvements. Happening to pass near the Creuzot ironworks he took the opportunity of paying a visit to them. M. Schneider was absent, but M. Bourdon received him and showed him over the works. Amongst other things he noticed a large crank of a marine engine, and, being struck by its size, asked how they had managed to forge it. Great was his astonishment when he was told that it was forged by his own steam-hammer! M. Bourdon explained to him that he had been very much struck by the design as shown to him in the scheme-book, and, immediately on returning to France, he had one constructed according to the plan as noted down in his own pocket-book at the time. This lent an unexpected interest to Nasmyth's visit; he was at once taken to see the steam-hammer at work, a big thumping child of his own brain. Some slight defects, due to M. Bourdon's oversight in making his notes of the invention, were now rectified according to the instructions of the inventor himself, who had often seen it piece by piece in thought, and knew what were the specially weak or specially strained places, and how consequently probable mishaps might be prevented. It was, however, to him an added delight to see it in actual material existence, in working life, in active exercise before him.

The success which he had predicted in the working of the machine was fully realized in practice, and he thought it best, by taking out a patent, to secure his rights in an invention which was now certain to be extensively adopted. This was a process which would cost £500, and his own money was already invested in his business. His partner was unwilling to advance money to this extent merely on a patent, when the returns seemed to him problematical. But his brother-in-law had often seen the designs, and had urged Nasmyth to take out a patent, and not to show the invention so freely to others, who might deprive him of the advantages which justly belonged to him. To this brother-in-law he therefore now appealed for assistance. He found him willing to advance the money, and undertook to repay him from the first profits of the sale of the steam-hammer, and to give him a share in it. The patent was taken out in June, 1842.

The steam-hammer consists of an arrangement for lifting a heavy mass of iron by means of the powerful motor steam, and directing it in its descent upon the material placed on the anvil block beneath it. This was accomplished by fixing a strong steam-cylinder in an inverted position—that is, with the piston-rod below—immediately over the anvil block, and attaching the heavy mass which was to perform the work of the hammer-head to the piston-rod, so that the two moved vertically up and down together when the machine was in action. It was so designed that it could be held in marvellous control by the workmen in charge. The hammer can descend so gently that it will just crack the shell of an egg placed in an egg-cup on the anvil block; it can be arrested at any point in its descent; it can give a blow that will shake the parish, and it can pour these powerful blows at the rate of eighty a minute. For stamping large pieces of metal into any chosen pattern it soon proved invaluable, as well as for its primary purpose of forging great masses of iron.

When Nasmyth had taken out his patent, he at once proceeded to fit up a steam-hammer for his own use; and it was employed regularly in the work of the foundry. At that time, too, the iron trade was recovering from its recent depression, and orders came in from all parts of the country, not only for steam-hammers, but for other machine tools which were able to take their part in doing the increased work for which there was a general demand. The patent for the new invention was also secured in the United States, by the assistance of some of Nasmyth's American friends.

The journey to France, of which the visit to Creuzot was a happy incident, was an enjoyable and profitable holiday. Nasmyth visited all the French dockyards, and this he did, not in a perfunctory way, but with a keen sense of interest in all that he saw, an interest not weakened by the fact that he there frequently saw machine tools which had been supplied by the Bridgewater Foundry, doing their work in good style. This professional side of his expedition was supplemented by the delight he experienced in seeing the quaint and noble architecture of these old towns, and the superior workmanship that characterized it; and also by his enjoyment of the natural scenery, which appealed to his sound artistic instincts. From France he passed on, for business and pleasure, to Italy; but everywhere he made it a rule to place business first and pleasure second. At Naples he stayed some days, and ascended Vesuvius. He inspected the crater, and threw down a card of the Bridgewater Foundry, fastened to a piece of lava, as a mark of respect to Vulcan, the master of his craft. Vesuvius astonished and charmed him, and he brought away some sketches of its wonderful crater. He was thereafter to accomplish some very important researches on the subject of crater formations, as shown on the surface of our attendant star, the moon. The subject of volcanic action had attracted his attention even when he was a boy at Edinburgh, where the results of such operations in long past ages were still evident to those who had eyes to see, as he had learnt from the conversations of his father and his father's friends, when he accompanied them in their rambles round the city. It was this that, to some extent, prepared him thoroughly to enjoy his visit to

Vesuvius. But in many other ways he was equally prepared to make the most of a visit to these foreign countries. From his father he had heard an artist's glowing descriptions of Italian towns and scenery, and was, too, sufficiently acquainted with their history to enjoy the sight of an historical building without the objectionable chatter of a hare-brained guide. He thought it "much better to come with a mind prepared with some history to fall back upon, and thus be enabled to compare the past with the present, the living with the dead."

The journey thus served the double purpose of business and of pleasure; as a result of the first, the Bridgewater Foundry received a large increase of foreign orders; as the result of the second, Nasmyth returned to England thoroughly invigorated and full of energy for continuing his work, and also bringing with him, as usual, graphic records of the most striking and pleasant sights he had seen abroad.

Amongst others who were addressed on the merits of the steam-hammer, in the days when it was but a sketch on the pages of a scheme-book, was Sir Edward Parry, who, having won distinction in the Arctic Seas, was at that time head-director of the steam marine of England. Through him it was brought before the Admiralty Board; but the Admiralty were, as usual, cautious, with that caution which comes of a want of confidence in their own judgment. They admired but did not adopt the new invention. In 1843, after the Bridgewater

Foundry had sent steam-hammers to nearly every country in Europe, the Lords of the Admiralty thought they might safely make use of an invention whose merit was demonstrated so clearly. A deputation of officers visited Nasmyth at Patricroft, and he gave them the treat of an inspection of his works under his own guidance. The special object of their visit was to see the steam-hammer at work. They thoroughly satisfied themselves of its great usefulness, and one was ordered for the Devonport dockyard.

Nasmyth was present himself to superintend the erection of the steam-hammer at Devonport. On the day when it was set to work, the Lords of the Admiralty had just arrived on their annual visit of inspection. Nasmyth was introduced to them, and started the steam-hammer in their presence.

An important work was then in contemplation at Devonport. This was the extension of the docks, so as to accommodate the largest vessels of the royal navy. In order to accomplish this, it was proposed to shut out the tide from a long stretch of low-lying shore at Hamoaze, and to utilize the reclaimed space for the purpose. This involved an enormous amount of labour in pile-driving, so much, indeed, that there was a risk of the scheme proving impracticable. Nasmyth was consulted on this subject by the contractors for the work, and he was, as usual, ready with a suggestion. In fact, he had already thought over the subject, and taken out a patent for the application of steam to the purpose, by means of an adaptation of the steam-hammer. His suggestion delighted all who saw it, and he was requested to supply the necessary apparatus. This consisted of a steam-hammer to be fitted to the head of the pile by means of the guiding-box, in which the hammer-mass rose and fell; it could be raised or lowered by a strong chain by which it hung from a high crane. The crane was fitted with wheels, and ran along rails by the side of the piles, being worked by a steam-engine which was supplied with steam by the same boiler which supplied the cylinder of the steam-hammer. As the pile was driven down, the height of the cylinder above the boiler was constantly changing, and, to meet the necessities arising from this, Nasmyth devised a steam-pipe from one to the other with flexible steam-joints, so that the pipe could fold up in three places and accommodate itself to the distance of the cylinder.

The apparatus first steamed along the rails until it was alongside of the pile to be driven, which had previously been placed in position. The steam-hammer was then lowered until it rested on the pile. It was fastened to this, and the suspending chain was slackened so that the whole weight of the heavy steam-hammer, with the cylinder and guiding-box, might press downwards and aid the blows to be given. Then the hammer was set to work, and dealt its powerful blows at the rate of eighty a minute. The pile went down at once under this treatment, to the astonishment of the spectators.

On the day that the apparatus was first tried, the men in charge of the old-fashioned pile-driver gave a friendly challenge to Nasmyth to vie with them in driving down a pile. The steam-hammer was started on the shoulders of a pile seventy feet in length and eighteen inches square. The pile went down home with the greatest ease in four and a half minutes. That in charge of the challenging party was driven in after twelve hours' labour.

The work of the steam-hammer in this and in all its other applications was more reliable, and almost absurdly cheaper, than that of the machines and methods which it displaced; but the comparison in respect of efficiency could not have been better exhibited than in this competition at Hamoaze. No wonder the steam-hammer became Nasmyth's own favourite invention.

Success like this at Devonport brought in orders for steam pile-driving apparatus from many parts where considerable works were in progress, such as the High Level Bridge at Newcastle, the Border Bridge at Berwick-on-Tweed, the docks at Tynemouth, Birkenhead, and Grimsby, the Westminster Bridge, a great bridge at Kief, in Russia; the forts at Cronstadt, the embarrage of the Nile, and even works at Yokohama, in Japan.

Nasmyth's visit to Devonport led to his association with Sir George Colburn, Mr. Sydney Herbert, and Captain Brandreth in investigating the subject of testing chains. The theory had been put forward that chains were sometimes overstrained in the process of testing, and therefore weakened by it. Nasmyth devised experiments which were accepted as proving that this theory is groundless; he held that if a chain does not break under the proof strain, it is better rather than worse for it, however severe the test may be. The committee made many suggestions as the result of the work in which Nasmyth had taken part *con amore;* the suggestions were cordially acknowledged, but they were not all adopted. What a competent committee may recommend as useful, executive authorities often shelve as not necessary. Inventors must expect this treatment of much of their work; for it requires their kind of knowledge of the subject before there can be their conviction of the necessity or advisability of the improvement which they propose. The greatest men in all departments of excellence must put up with the fate, and sometimes the inconvenience, of being judged by men not so great as themselves.

In the autumn of 1842 Nasmyth was in communication with the directors of the Nuremberg and Munich Railroad, with a view to supplying locomotives for the working of their lines. This was the occasion of a visit to the mediæval city of Nuremberg, which gave him great pleasure, notwithstanding he thought fit to avoid the proffered contract for the railway engines. The city itself well repaid a visit. He was himself a workman who knew and loved good work, and with this Nuremburg abounded, in its architecture and its art, as also with memorials of the great artists who there had lived and laboured with distinguished success. Above all, he admired the place as having been the home of Albert Durer, a man whom he justly regarded as a universal genius, who was painter, sculptor, engraver, mathematician, and engineer, and occupies in the records of Germany a place like that of Leonardo da Vinci in those of Italy.

This journey was followed by one to St. Petersburg, at the commencement of the next year. Railways were beginning to spread their serviceable network over the continent of Europe, and a line had been constructed between St. Petersburg and Moscow. It was this line about which the engineers are said to have had disputes, in consequence of which the determination of its route was referred to the emperor's decision. His Imperial Majesty took a ruler, and drawing on a map a straight line between his two capitals, ordered that thus should the railroad run. The object of Nasmyth's journey was to obtain an order for locomotives for the new line; and he found the representatives of all the chief English firms there with like intent. But the emperor wisely preferred to fit up workshops in his own country, and to employ his own subjects, rather than be always dependent on foreigners, and the English manufacturers were therefore generally disappointed. Workshops suited to the requirement of the time, and able to work on a level with those of other countries, needed, however, the best machine tools, to which the great mechanical progress of preceding years was due. For these Nasmyth received a large order, and they were accordingly supplied from the Bridgewater Foundry.

It is needless to state that Nasmyth found this trip, like his previous visits to the continent, a source of great enjoyment. He was on the look-out for works and sights of interest; he was keenly observant; and he was so well informed, as well as so widely sympathetic, that many objects served to excite his admiration that would have been passed by as commonplace and uninteresting by less qualified travellers, of whom it may be guessed that the element of the commonplace is more in them, the observers, than in the things they see. Moreover, he was of those who believe that it is always good to add to their stock of knowledge, and he was sure to make a mental note, or a graphic sketch or other memorandum of anything that he saw, if it looked likely to give him food for thought. He was thus in all respects qualified to be a traveller. The man who finds journeys in strange countries, and amongst cities that have risen to fame, dull and uninteresting, is not made to travel; he can be dull and uninterested in his own home with far less trouble.

Amongst the more memorable incidents of Nasmyth's visit to St. Petersburg was his introduction to the astronomer Otto Struve, by whom he was shown the excellent arrangements and the fine instruments of the great observatory at Pulkowa, fitted up as it was with imperial liberality by the Emperor Nicholas. Struve was then an old man, but he was still the ardent astronomer; and his visitor, who never seemed to engage in anything except with ardour, saw and understood the astronomical instruments, their application, and the results of their use; and estimated the pleasures of an astronomer's work as amongst the most attractive to be found. To its attractions he had already yielded, and it afterwards became his favourite pursuit, to the no small advantage of astronomical discovery.

He was much impressed with the excellent work turned out by the Russian workmen, though these were chiefly serfs; and he thought from what he saw of their workmanship that Russia must have a great future before it, judging that excellence in the work of ordinary workmen is an infallible sign of excellence in the national character. There is, however, one thing necessary besides that good quality of accuracy in workmanship; there must also be originality and boldness in design. It is this that, in giving England Watt, Stephenson, and Nasmyth, has given her an exceptional start in the path of mechanical progress. It is well that an army should be drilled to act with precision, but it also needs good leaders before its success can be prophesied.

After a brief stay in St. Petersburg, Nasmyth had the pleasure of a voyage down the Baltic, past its granite islands, whose pine-trees dipped their green branches in the clear waters of the sea as they steamed by, to Stockholm. Having done the business which took him there, he went on to see the famous Dannemora Iron Mines at Osterby, where a great abyss shows how vast a mass of solid rock has been quarried out for the sake of the rich ironstone it contains. It is to the use of this splendid iron that Sheffield is said to be chiefly indebted for its reputation.

In his wanderings in Sweden, Nasmyth was often at a loss for words of human speech with which to address the country innkeepers when he needed accommodation. On these occasions he would pull out his sketch-book and make a rapid drawing of a table provided with the needed repast, or of anything which served to intimate his immediate want. He found that a sketch went further than a sentence, for it at once kindled a friendly feeling between him and his hosts.

He next passed on to Copenhagen, where his astronomical tastes made him look with special interest on any memorials of that great pioneer of modern astronomical observation, Tycho Brahé. He found a contemporary portrait of him in the town-hall, and paid a visit of reverence to the round tower on the top of which are the remains of Brahé's first observatory, where he made and used the astronomical instruments which he had invented. These were all afterwards taken away to the island of Hveen, where the ruins of his castle and observatory are still to be seen.

From Copenhagen he proceeded home by way of Hamburg, Amsterdam, and Rotterdam, and found when he arrived at Patricroft that the foundry was in a most flourishing condition, and that orders were coming in from all parts of the civilized world, where the fame of the excellence of its work was spread abroad.

The revolution that was being effected by the introduction of machine tools was, like all revolutions, sure to meet with resistance. It is not too much to say that by its means a little one became a thousand; a boy's attention was all that was required to keep at work an elaborate and powerful machine, able to do as much as many skilled labourers, and to do it more efficiently. The quantity and quality of the work produced at the same expenditure of labour was incalculably improved. As a natural correlative of this, the demand for articles so manufactured with greater ease and less cost vastly increased, so that not fewer but actually more labourers and workmen were necessary than before, although the labour of each was made so much more productive. But the workmen, or rather the trade associations of which they were in some cases but ignorant members, looked upon the introduction of the machine tools as tending to an exclusion of themselves from their accustomed labour and from its profits. It was found by the manufacturers that one man could look after more than one machine, so simple was the management required, and that he was perfectly willing to do so for a small increase to his weekly wage for every additional machine intrusted to him. The unionists demanded that there should be to every machine one man, who must be a union man, and must be paid full union wages. They brought their great hostile operation of strikes to bear upon one firm after the other, but in the end they had to give up the contest. Whilst this conflict was progressing, the Bridgewater Foundry was able to keep its workmen at full work. The unionist workmen had left, on the commands of their council, but their place was filled with intelligent men who were afforded every encouragement to work honestly and well, and who received no advancement but such as they were recommended to by their own worth. A good workman obtained far more from a firm like that of Nasmyth and Gaskell than he could ever have received had the principles of trades' unions been triumphant; a moderate workman was at least as well off, and only an incompetent workman was at a disadvantage. The principles of justice which are implanted within every man approve of the assignment of the smallest prizes, or none, to incompetence rather than to high deserts; the collocation of little worth and little pay is natural. Nasmyth felt this when he astonished a deputation of unionists by the announcement that he preferred employing a man who had acquired the requisite mechanical skill in two years rather than another who was so stupid as to require seven years' teaching. It may be often necessary for one class of people to take combined action in their own interest against the encroachments of another class upon their rights, but the principles enunciated by the trades' unions were founded on a mistake, and do not commend themselves to common sense, nor is their application supported by experience. This, too, is certain, that whatever might be the case with other firms, there was no just complaint against employers like Nasmyth and Gaskell. They desired to make their men so contented that they should never be tempted "to look over the hedge" at greater attractions elsewhere.

The Bridgewater Foundry lived through this anxious crisis without suffering any harm; the one result to them was the successful reassertion of their favourite principle of free trade in ability.

At this time Nasmyth was endeavouring to extend the use of small steam-engines in factories. He thought that it was better to have the steam-power applied directly to the individual machines, the steam being conveyed to all from a large central boiler, rather than to connect all with one central steam-engine by a very complicated and expensive system of shafting and gearing. The advantages of this arrangement were so generally acknowledged that it was speedily adopted in many branches of manufacture. The fruits were reaped very largely by the Bridgewater Foundry.

Some variety was lent to Nasmyth's technical work by an order which he received from the

Russian Government, in 1849, to provide the machinery for a large rope-factory at the naval arsenal of Nicolaiev, on the Black Sea. This gave him occasion to study the whole subject of the application of machinery to rope-making, which he found full of interest. New difficulties presented themselves, which he set himself to overcome. To understand and to overcome difficulties in mechanical work is the part of an inventor, and in the consciousness of this success lies the chief pleasure of inventing; this is on the testimony of James Nasmyth himself. He was to have accompanied the Russian Admiral Kornileff on a trial trip in a magnificent steamer which had been constructed in England for the Russian Government, and would then have had the opportunity of seeing his machinery at work at Nicolaiev; but the near prospect of war, soon to be realized in the Crimea, deprived him of this treat. When the war broke out, Admiral Kornileff was one of the first to fall, being killed whilst engaged in placing some guns for the defence of Sebastopol.

Like James Watt, James Nasmyth was never without a hobby for the occupation and amusement of his leisure. His skill with the pencil was often exercised to produce results whose charm won the praise of all who saw them. Fanciful sketches were added to drawings of scenery or towns he had visited; some of the prettiest and most imaginative of these, such as "The Fairies" and "The Astrologer's Tower," are reproduced in his autobiography.

One essential element of the highest praise that can be accorded to a work of art is the acknowledgment that it occasions to the observer a pleasure comparable with that experienced by the artist in its production; and, notwithstanding the delight which Nasmyth took in all his work, this praise is due to many of his beautiful drawings.

Of all the pursuits of his leisure there was none so fascinating as practical astronomy. He had learnt from his father to admire the discoveries of this science, and before he had left Edinburgh he had made a small reflecting telescope. Again, after his first English holiday, when he returned to London, he heard from Maudsley of his visit to the royal observatory at Berlin, which had so pleased him that he was resolved to erect a large telescope of his own. In carrying out this object Maudsley was assisted by Nasmyth, who suggested a reflecting telescope, as being more easily made than a refractor, on account of the difficulty of obtaining large lenses in adequate perfection. The speculum for the reflector could with care be prepared in their own workshop, and this Nasmyth undertook, having before this thought carefully over the best method of accomplishing such a task.

When Nasmyth settled down in his home at Patricroft, he provided himself with a good reflecting telescope, the work of his own hands from end to end, and by repeated practice became a first-rate astronomical observer. In the year 1842 he judged himself competent to undertake work of independent research, and to attempt to make a real contribution to the progress of astronomical knowledge. He therefore studied most closely, by means of a new and admirable instrument, the surface of the moon. He mastered every detail, and mapped the whole out most accurately. This was, however' but the first step. He knew that only a partial idea of a region, whether in the moon above or the earth beneath, can be obtained from a map. As an artist, he desired to know how the country looked, and to make a picture of the strange landscape. He possessed to a remarkable idea the faculty of picturing objects from a plan. He had often in his mind seen his steam-hammer at work as a solid object, he had imagined it as though it existed, before ever his eyes saw it in tangible form at Creuzot. This may be the faculty of the artist or the faculty of the geometrician, according to the uses to which it is put. It was a faculty which was well developed in Nasmyth. From pictures of different parts of the moon's surface he proceeded to modelling its most remarkable features. He thus thoroughly explored tracts equal in area to about one-thirtieth of the earth's surface—truly one of the greatest and most conscientious explorers!

This work was followed by investigations into the physical conditions to which the moon is subject; the absence of air and water, and the results of these facts. He also discussed the causes to which the present state of the moon is due;

from which he was led to consider some of the geological phenomena presented by the earth. He gave an account of these important researches to the British Association, at its meeting in his own romantic city of Edinburgh, in the year 1850; his natural enthusiasm and his clear way of explaining the clear thoughts he had in his head on the subject, made his lecture one of the most interesting incidents, and himself one of the most popular members, at the meeting.

The next year is memorable for the first Great Exhibition. Nasmyth was honoured by the award of a Council medal for his steam-hammer, a good specimen of which he exhibited; by a medal for a novel and compact arrangement of the parts of a steam-engine, suggested to him by the shape of his own steam-hammer; and, above all, by a prize medal for his researches on the moon, as shown in the drawings he contributed. With this recognition of his astronomical work he was specially pleased; it was another proof that his genius did not run in a narrow groove. The description of his work, as given by the jurors, was in these words: "Mr. Nasmyth exhibits a well-delineated map of the moon on a large scale, which is drawn with great accuracy, the irregularities upon the surface being shown with much force and spirit; also separate and enlarged representations of certain portions of the moon as seen through a powerful telescope: they are all good in detail, and very effective." Shortly afterwards he had an opportunity of laying these drawings before the Queen and the Prince Consort, and of explaining to them all the wonderful facts which he had discovered with regard to our interesting satellite. His continued study of astronomy was furthered by the application of his mechanical knowledge to improve the instruments; amongst the most useful of these improvements was an ingenious contrivance for the mounting of his big reflecting telescope, so that he could direct it to any part of the heavens without rising from his seat, instead of having to mount to the eye-piece by a ladder, as had previously been necessary in observations of stars at a considerable altitude.

Among his contributions to speculative astronomy is a note on the origin of solar light, remarkable as anticipating to some extent, and in general terms, the theory put forward by Dr. C. W. Siemens in 1882. He advanced the theory that space is filled with an element which blazes up when it comes into contact with the solar surface; and that the energy of the sun is therefore as inexhaustible as space itself. To account for the apparently undiminished energy of the sun within historic and long prehistoric periods, has been a problem to puzzle philosophers. Dr. Siemens suggested that space is filled with gaseous matter which is dissociated, or resolved into its elements, by the heat of the sun, when it is in a suitable state of rarefaction; that this chemically uncombined mixture is brought to the surface of the sun by the currents which the rotating sun creates around it;

and there burns, and is whirled out into space in the course of the same currents, having been re-formed by the burning into a chemical compound in readiness for the dissociating action of the radiant heat when a sufficient degree of attenuation has been reached. This process being repeated in a cycle with an imperceptible loss of energy, the sun continues to shine with undiminishing splendour.

The theory in its more developed form, as worked out by Dr. Siemens, has been the subject of much discussion and controversy; and it cannot yet be regarded as accepted.

It may be said that Nasmyth retired from business in order to follow up his astronomical researches. But for this all-absorbing pursuit he would not have found in retirement the active mental occupation which alone made it attractive to him.

He brought his successes as a mechanician to a worthy close by taking out a patent for puddling iron by a process in many essential points the same as that with which the name of Bessemer is associated. The similarity of the two methods was acknowledged by Sir Henry Bessemer, after the meeting of the British Association at Cheltenham, where he announced and explained his own invention. He made Nasmyth an offer of one-third share in the profits of his patent. The offer was thankfully declined. Nasmyth was, as he says, about to take down the signboard and leave business; not even this lure could keep him longer at his old occupation. Henceforth he is the astronomer. At the end of that year, 1856, he retired to a comfortable home at Penshurst, in Kent.

Nasmyth's further astronomical researches resulted in the accumulation of more information about the moon, which, together with previous results, he collected and published in an interesting form, under the name of "The Moon, considered as a Planet, a World, and a Satellite."

But he also turned his telescope on the sun, and made there a discovery which alone would have perpetuated his name. He was the first to discern that the face of the sun appears to be covered everywhere, except in the depths of the sun-spots, with bright bodies of apparently uniform size, and shaped regularly like willow leaves or rice grains, crossing one another in all directions and moving over the surface. The existence of these forms has been verified by observers in Europe and America, but they present as yet an unsolved mystery. As Sir John Herschel remarked, they must possess a great deal of rigidity to retain their shapes in the midst of the rapid and violent movements of the solar atmosphere, especially in the neighbourhood of sun-spots.

With this we may end our story of the happy, useful, and successful life of James Nasmyth.

If the reader, having followed us in our praises of the exact workmanship of Watt and Nasmyth, should turn to the second volume of Ruskin's

"Stones of Venice," he will find much strong and fervent language used in denunciation of the very excellence we have extolled; applied, in the first instance, to the work of the artist, but extended to that of the artisan also. In the case of Watt and Nasmyth this perfection in metal-work was the foundation of their future service to the world. The same accuracy that distinguished themselves they required for practical purposes from the hands of their workmen; it is the consequent growth and extension of mechanical excellence that have enabled the inventions of rare genius to become working realities for the common world. There is, then, a necessity in the demand for exact workmanship, and this is its first justification.

But Ruskin says that we should above anything look for the thoughtful part which exists in all our workmen, and to get that out of them, whatever we lose for it, whatever faults and errors we are obliged to take with it; and that the demand for perfection of manual skill is inconsistent with this, because it lowers a man to the level of a tool.

If, however, we do not jump quite so hastily to a conclusion, but rely upon investigation, rather than upon denunciation which is the prerogative of the greatest teachers only, it will occur to us that the essential condition of perfect manual performance is the utmost care on the part of the workman. To encourage carefulness is to encourage thought; to be indifferent to excellence of finish in work is to allow carelessness, and though it may also allow room for variation and originality, it scarcely encourages these, for it does not primarily insist upon thoughtfulness in little things.

What, then, is the effect of this requirement on the character of our workmen and of their achievements? It should seem to be a great thing to teach an increasing number of human beings, through the continual lesson of their daily toil, the importance of doing all that they have to do with care and precision. Such a life-long education as this must have an influence on their character, must tend to improve the habits of those who undergo it. There may be other conflicting tendencies in operation; but this at least is not in itself an evil. Nor is there harm in the acquisition of the consummate knowledge which is needed for consummate finish in all parts of their work, or in the one part of the work which falls to their lot. It is only after this that, having learnt well what is good, their minds are left free and duly prepared to suggest what may yet be better. Some preliminary knowledge acquired after much pains, good habits of carefulness induced at the same time by constant practice, and a mind naturally willing to use the opportunities for exercise placed in its way; these are the equipments of progress. The last is independent of all systems of education, the other two would appear to be well secured by the modern systems of technical training, which provide them for multitudes where formerly they were the privilege of a few.

Further, what we might thus have expected has been realized. The demand for perfect manual skill has not ended in dulling the workman's power of invention; it has, by such action as we have sketched, given it something to work upon, strengthened it, made it more reliable, and always more to the purpose. During the last hundred years, since the importance of precise and exact workmanship was forced upon the attention of Watt, and through him upon the world, the spirit of invention and of continual variation and improvement has been more active than ever before; and its activity has been chiefly and almost entirely manifested in those who had begun by learning to be first-rate skilled workmen themselves. The increase in the amount of work to be done has besides increased the number of workmen; it has enlarged the field from which the useful, originative workers could be drawn, as well as multiplied their effectiveness. Thought has not been killed; it has been quickened.

CHAPTER IX.

SIR JOSEPH WHITWORTH.

"The most celebrated mechanician of this country, he has invented a whole set of machine-tools that have revolutionised the labours of our workshops; he has invented means for improving the metal of which tools are usually made; and he has provided with princely liberality for the improvement of that technical education upon which depends the success of future generations in the skilful use of tools."—W. T. JEANS.*

THE story of successive inventions shows more and more the intimate relationship between the accurate construction of machinery and its practical efficiency. Each fresh advance in invention has had to be associated with a corresponding improvement in execution, before it could be exhibited to advantage in a working form. We have seen that the beautiful engines of the present day are indebted for the very possibility of their existence to the nearer and ever nearer approach to perfection in

* *Creators of the Age of Steel.* To this interesting volume I am indebted for full information about Sir Joseph Whitworth's work.

the achievements of the modern workshop. Those who learnt this lesson first and most thoroughly were those whose work and hopes were most affected by its truth, the mechanicians who were taught by scanty hints and sharp foresight what they have placed before us in the more convincing light of the full experience which they have gained.

The proverb says that it is the bad workman who throws the blame on his tools. It would, however, be wrong to infer from this that all tools are equal in the hands of a good workman. The difference between the bad workman and the good is this, that while the one blames his tools, sometimes rightly and sometimes wrongly, the other sets to work to improve them when their shortcomings interfere with the excellence of his handiwork. Both perceive that exact tools are necessary to exact workmanship; but the one is helpless if he finds his tools at fault, while the other finds in such a circumstance only another suggestion for exercising his ingenuity. "Make the tree good and its fruit good" is a lesson drawn from the work of the great Artisan who made the worlds. "Make the tool true and its work true" is the same lesson as illustrated in the workshops of His creatures.

One of the first necessities of modern mechanics is the power to produce true plane surfaces. Another requisite is an exact measuring apparatus, in order that the workman may have a gauge by which to test the accuracy of his work, and to indicate its errors. In addressing the Institution of Mechanical Engineers in 1856, Sir Joseph Whitworth said: "I cannot too strongly impress on this institution, and upon all concerned with mechanism, the vast importance of possessing a true plane as a standard of reference. All excellence of workmanship depends upon it. Next in importance to the true plane is the power of measurement." He was teaching a lesson he had himself thoroughly learnt in the school of experience. Mr. Goodeve, in the chapter which he contributed to the Handbook of the Loan Collection of Scientific Apparatus, 1876, laid due stress on the same two points, declaring that the power of constructing true surfaces and the power of measurement are the two things which have combined to give us the machinery of the present day. That exhibition contained a splendid specimen of a surface plate, lent by Sir J. Whitworth and Co.—"that primary surface upon which we rely in the construction of machinery, being in effect the closest approximation to an absolutely plane surface which has yet been attained." Sir J. Whitworth also exhibited measuring machines capable of measureing differences so small as the millionth part of an inch. He is therefore to be credited with an important part in modern mechanical progress.

Joseph Whitworth was born at Stockport, in Cheshire, on the 21st of December, 1803. He received his early education at home from his father. When he was twelve years of age he was sent to school for eighteen months at Idle, near Leeds.

His school-days thus quickly over, his technical education promptly commenced. He was placed in a Derbyshire cotton mill belonging to an uncle, and there made his first practical acquaintance with machinery. After four years in the mill he was transferred, at the age of eighteen, to a Manchester workshop. Here he worked to such good purpose, that, when in three years' time he removed to London, he found himself able to take a place amongst the skilled workmen of Maudsley and Clement's workshops, where, indeed, he was esteemed the cleverest worker. It was here that machine-tools, and the means adopted to improve them, could best be studied, and Joseph Whitworth soon showed that he appreciated the importance of perfect tools as a condition of perfect work, and aimed first at producing exact plane surfaces to suit the requirements of the machine tools of the workshop. This was first necessary before any machines could be relied upon to generate other plane surfaces. He spent the energies of his earlier manhood in inventing and in perfectly constructing machinery for the production of true planes, such as were at that very time wanted for the valves of steam-engines, the tables of printing presses, stereotype plates, surface plates, slides of all kinds; but could not be supplied of sufficient accuracy.

It might have been fancied that to seek after a mechanically true plane surface would be the part of a scientific enthusiast in love with the ideally perfect, rather than with the practically useful, and that less perfection would satisfy all practical needs. A student of mechanics who had no useful object before him, might conceivably have attacked the problem of producing accurate surfaces of any form, and have been content with seeing the material embodiment of a shape that had been before but imperfectly grasped by his mind, and many surfaces have been modelled in this way from a knowledge of their equation or geometrical properties. Events have, however, shown that the advance towards ideal perfection in the surface of a plate, on account of its being a necessary preliminary to mechanical progress, has ever been intimately associated with it, and has been made by men eminently practical; by men who are not content with setting up the true plane they have made merely as a beautiful thing to admire, but know how at once to make use of its exceptional excellence for work which was previously beyond the range of the practical mechanician. The originator of the first true planes knew well, as he persevered in his endeavours, that his success would be immediately and abundantly fruitful in its many applications to machinery. Sir Joseph Whitworth, before he was thirty years old, succeeded in producing plane surfaces with an accuracy never before attained, and this result was of essential service to him in nearly all the machines which he subsequently invented. He then returned to Manchester, in 1833; and seven years later his process was brought to perfection and fully described by him.

When Sir Joseph Whitworth went to London there was no kind of planing machine in existence; the chisel, the hammer, and the file were the only tools used for the purpose. The method of working plane surfaces for use in machinery was therefore rude, unreliable, tedious, and expensive. When a model existed, a thin coating of colouring matter was laid over the new plate; when this was rubbed by the model plate, the inequalities in its surface became apparent, and were reduced by further grinding until the new plate agreed, as nearly as might be, with the pattern. It was in 1830 that Whitworth designed his edge-planing machine. He has made one capable of giving a straight cut of forty feet in length. The bed plates of this machine are fifty feet long, and its grooves are considered the longest true planes in existence. So exactly can plane surface plates be produced by this machine, that, when they are laid on one another, and pressed together to drive out the layer of intervening air, they adhere to one another, and require great force to separate them. That is to say, the plates are so near to one another as to call into play the forces of cohesion which are imperceptible at ordinary distances. A few inequalities on the two surfaces would have kept them so far apart that these cohesive forces would not have come into action, and yet the surfaces would have seemed smooth enough to sight and touch.

Confident that he had already achieved some valuable successes, and full of determination to follow them up, and to make the most of any other ideas that might spring up in his mind, on his return to Manchester in 1833 he unostentatiously enough proclaimed himself with no more pretentious title than "Joseph Whitworth, tool-maker, from London." Those who do the most work, the practical geniuses of the world, are not fond of high-sounding titles in describing their office or their work. "I'm only the engine-man from Killingworth, that's what I am," said George Stephenson, and the introduction probably carried more weight than if he had described himself as the most advanced student of the application of steam to locomotion. So the flourish of a boast was not numbered amongst Joseph Whitworth's working tools; it would have been as much out of place in his workshop as gold fittings to a steam-engine. Tool-maker he was, and he amply justified his assumption of this title.

His workmen at first opposed the introduction of the new planing machines; but fortunately opposition takes some little time to gather to a head, and meantime the tools were tried. This vanquished opposition; the workmen saw and were conquered.

In continuing his quest after the most perfect accuracy in machinery, Sir Joseph Whitworth found it necessary to devise measuring apparatus far more exact than any previously in existence. It was impossible to give unprecedented precision to his work unless he could measure with unprecedented exactness the smallest departures from the required form. By the machine which he invented for use in the workshop, he was able to determine differences so small as the ten thousandth part of an inch, and by a still more accurate construction he was able to measure even to the millionth part of an inch.

We may have a general idea that these measures of length must be extremely minute. A little calculation will help the mind in its wonder at the achievement. Any ordinary book will be found to contain from three hundred to five hundred pages to an inch of thickness. If we were to take up a book with four hundred pages to the inch the paper would be thin. The thickness of one leaf of it would, however, be as much as the two hundredth part of an inch. Whitworth's workshop machine could indicate by clearly marked divisions lengths as small as the fiftieth part of the thickness of such a sheet of paper, and his millionth machine could as clearly detect differences as minute as the five thousandth part of that thickness. If paper could be made as thin as these small measurements and strong enough to bear printing, our libraries would assume a most convenient compactness. If the binding could be reduced in the same proportion we should be able to put five thousand volumes where now we put one, and the bulkiest book would, with all its pages and without altering the type, be thinner than a leaf of the present volume.

Inexactness to the extent of even one of the divisions of the workshop measuring machine may appear to be but a trifle, and this may be admitted to be so if a trifle be defined as a small thing which becomes important when neglected. This minute difference in the diameter of a steel cylinder is enough to decide whether it will fit closely or loosely in a hollow cylinder. Sir Joseph Whitworth has exhibited a tube of diameter ·577 inch, and two short cylinders one of the same diameter as the tube and the other falling short of it by the fiftieth part of the thickness of such a sheet of paper as is mentioned above. The space left between the cylinders and the tube in the second case was therefore only the hundredth part of the distance from one side of that sheet of paper straight through to the other. Yet this cylinder seemed so loose in comparison with the first that it scarcely appeared to fit the tube at all until it was oiled, and then the oil served to fill up the vacant space. Lubrication is necessary, too, in the case of the accurately fitting cylinder; for if this be driven dry into the tube, its particles get entangled in those of the inside surface of the tube, and it is impossible to separate them after they have been a little time in contact; whereas if oil is used it will work easily.

The true planes are so exact that even the measuring machine cannot detect any deviation from truth.

Sir Joseph Whitworth was the first mechanician to take out a patent for machine tools. Between the years 1834 and 1849, he obtained fifteen patents, or an average of one a year. It was in those days a costly privilege to procure a patent, involving an expense of £500 or £600. These patents were therefore not taken out in the case of every trifling improvement, but were the record of considerable mechanical successes.

If a number of similar articles are made by hand, it is impossible not to give them endless and needless variety of shape and size. When they are wanted for mechanical purposes, in which they are subject to the necessity of frequent repairs, great inconvenience and expense must result from their want of uniformity. This inconvenience has to be endured, for the hand, work it never so cunningly, cannot attain the undeviating certainty which alone could remedy it. Even some advance towards a partial remedy might necessitate such exceptionally skilled labour that the expense would make its adoption commercially inexpedient. If, on the other hand, a number of like articles are made by a good machine, it is easiest, quickest, and cheapest to make them to gauge, for all practical purposes exactly like one another, and the advantage is much everyway. We have seen this in the case of that universally useful little tightener and fastener, the screw. Sir Joseph Whitworth followed up the suggestions made to secure uniformity in the manufacture of these; and the dies for producing them, now everywhere in use, were originally supplied from his workshop in Manchester. His early employment in a cotton mill enabled him to introduce there, on the same principle, machine-made spindles instead of the hand-made articles previously in use. It had been the custom to make the spindles separately by hand, and to fit each separately into the bolster; when one was damaged its place had to be specially supplied; any spindle sent at haphazard would probably not fit the place for which it was required. Now matters are simplified. The machine has been set to work to make spindles. They are now all made to gauge and are interchangeable; new spindles are obtained with ease, and without superfluous anxiety that they will not fit. The annoyances and interruptions of toiling man are diminished, and the blessing does not stop with him, for others are enabled to enjoy the fruit of his toil more easily.

We are now accustomed to machines for sweeping the streets of our large towns. It was Sir Joseph Whitworth who first made and patented these, in 1842, and with such good result that Manchester speedily exchanged the notoriety of being the dirtiest for the reputation of being the cleanest town in England.

The verdict of the Great Exhibition of 1851 showed that Joseph Whitworth, tool-maker, was fully entitled to the designation he had chosen. He contributed to the class of engineering tools specimens of first-rate excellence under each head. He received the Council's medal for his engineers' machine tools, his measuring machine, and his knitting and other machines. The importance of the Great Exhibition is apparent in many ways; we are certainly impressed by it when we consider how all the best work of the distinguished mechanicians of the time found its way there for criticism, comparison, and reward. The honour of success in the Great Exhibition of all nations was a mark of merit coveted even by the best, and of acknowledged value in the eyes of all. Whether it contributed to the great march of progress or not, whether or not from it diverged currents of quickened energy to foster civilisation and to incline the nations to peace, it derives no inconsiderable importance from the fact that to it converged the streams of past progress bearing to one centre the achievements of successful effort.

The powers which made these wonderful instruments of precision for the workshop and the laboratory could not be restricted to peaceful uses only. War offers motives as powerful, if not as continuous, as those of Peace, to call out the utmost resources of rivals. The possession of armaments superior in quality as well as in quantity is a factor of success, as important as the soldierlike qualities of the men. It was at the time of the Crimean war that Sir Joseph Whitworth was turned aside from inventing machines for the manufacturer to perfecting engines of destruction. At that time the Enfield rifle was far superior to any previous hand-gun, and its achievements were regarded as effecting a revolution in modern warfare.

A rifle is a musket with the barrel spirally grooved in order to give the bullet a rotary motion; this spiral grooving is called the rifling of the gun. Rifles appear to have been known on the Continent as early as the middle of the 17th century, but they were not introduced into the British Army before the American Revolutionary War.

There was a serious defect in the Enfield rifle. It was hand-made. Accordingly, when there was an extraordinary demand for them, the makers could not supply them quickly enough. The Government then wanted a million rifles, and it would have taken twenty years to complete the order with the then existing means of production. In the days of steam locomotion and other rapidities of production and action, this kind of delay could not be tolerated. Then again there was the necessary failing of all hand-made things. No two rifles were exactly alike; any two that might be to the eye precisely similar were found to have very different powers when in use; one would turn out to be an excellent instrument, its fellow might prove very inferior, and no one could tell why.

To meet the difficulty of insufficient supply, the Government proposed to build a small-arms factory of its own; but in the course of preliminary inquiries that were made with this object, Sir J. Whitworth laid such emphasis on the second difficulty—the uncertain quality of hand-made guns—that the Government abandoned its project, and requested him to furnish designs for a complete set of rifle-making machinery. This he declared to be impracticable until he had fathomed the mystery of the rifle by careful investigation and experiment. When he should discover the best shape of the barrel, the most suitable size of the bore, the most effective amount of twist to give to the rifling, then he would be ready to contrive machinery for turning out the rifle embodying all these excellences. To make machinery for one kind of rifle, and then to find out before another war came round that on account of its proved inferiority the army must be re-armed with a new weapon, he represented as more hasty than economical. At the same time he offered to conduct the necessary experiments, provided Government would pay their cost. This offer was not at first accepted, on account of its expensiveness; but at length, in May, 1854, the Lords of the Treasury sanctioned the experiments. Owing to some accidental delay, it was not till March, 1855, that Sir J. Whitworth was able to commence his experiments in a shooting gallery which he had erected for the purpose at Rusholme. After two years' arduous work he was able to announce that he had satisfactorily solved the problem upon which he had been engaged, and that he had found the Enfield rifle wrong in every particular. The Enfield rifle had a twist of one complete turn in seventy-eight inches, the diameter of its bore was ·577 inch, the bore was cylindrical with grooves. He discovered that the best twist was one turn in twenty inches with a minimum diameter of barrel of ·45 inch, and the bore of his new rifle was hexagonal with rounded corners. A public trial of his new rifle was made to compare it with the Government musket, when its superiority was clearly established. The deviation of a bullet from the Enfield rifle at 800 yards was more than four feet, of the Whitworth rifle barely one foot; and similar differences were exhibited at other distances. The Whitworth rifle penetrated thirty-four half-inch elm boards, while the Enfield rifle could not make way through more than twelve.

In order fully to investigate the problem before him, it was necessary to discuss also the shape and make of the bullet, and the quality of the powder to be used. The powder then in use he found to be ill-suited to the purpose, and he adopted a more effective kind. Experiment showed him that it was best to use, not a spherical bullet, but one about three times as long as the diameter of its section; that the adoption of a conical point in front was an improvement; and that steel could, with the high rotations generated by the rifling, be advantageously employed. With these changes, the bullet advanced steadily, point foremost, keeping its balance throughout its flight. It was shown that longer bullets swung round and continually changed front until they struck the mark, and the blow, instead of being concentrated at the conical point, was diffused over a larger surface, and was consequently less effective. The rate of rotation produced in the bullets was eight times as great as that which would have been considered extremely high in any piece of machinery. One of these projectiles performed about a thousand revolutions in one second of time on its way from the mouth of the gun. It was, in fact, a little drilling machine engaged in work of so great importance that it must be done, whether the machine survive the effort or not. It was, therefore, not necessary to limit the speed of rotation in order to preserve the machine from damage—a consideration not superfluous in the case of ordinary machinery. The effect of this drill, advancing point foremost by reason of the high rotation imparted to a body of its shape, and striking armour plates of strength then thought reliable, was marvellous. It pierced iron plates half an inch thick, not only point blank, but when it struck them at a great inclination. Iron plates seemed to present no greater obstacle to it than the wooden planks to the older forms of bullet.

The object of the modern gunsman is not simply to throw a hard thing with great force against the mark; at first it was not known in what other way to add to the effectiveness of the blow. There are now methods of making the bullet a mechanical success as a powerful penetrating instrument. It was from this point of view that Sir Joseph Whitworth attacked the problem, and it was one whose difficulties his previous training gave him every promise of combating with success; and the event did not belie this promise. He did not take any delight in the task merely as adding to the dread instruments of war one more powerful and terrible than any previously in use. Speaking later on this subject, but with special reference to the shells which he afterwards invented, he declared that if it were not that the increased destructiveness of war must tend to shorten its duration and diminish its frequency—thus saving human life—the invention of his projectiles could hardly be justified; but believing in the really pacific influence of the most powerful means of defence, he considered himself justified in calling his projectiles anti-war shells. Perhaps the name and the reasoning sound a little forced to those who have not been led to them by the same path as that which Sir Joseph Whitworth followed. Perhaps, too, the most satisfactory apology is that of patriotism. He must have felt a stimulus from the fact, apparent so conspicuously to himself, that his services in this department were needed by his own country. It was at the suggestion of Government that he directed his attention to these enquiries, and his labours seemed but a response to Nelson's grand signal at Trafalgar, "England expects every man to do his duty," a signal which it was worth living to make, worth being an Englishman to welcome with thrill of pride and of resolve. The first opportunity to use his improvements would necessarily fall to the English Government. In that case he might reasonably hope that his guns would be primarily and chiefly means of defence rather than weapons of offence. At any rate he had evidently to pass through some mental struggle before he allowed himself to devote his energy and ingenuity to the improvement of modern artillery. When his first disinclinations had been overcome, he found the problem profoundly interesting to himself on the mechanical side, and was therefore willing to devote thousands of pounds of his own private fortune to its laborious elucidation. He mastered the principles of the rifle in a way that had never been attempted before. He then constructed a rifle, improving gun, powder, and shot, so as to bring the result nearer to the ideal which his investigations indicated. "It would be difficult," says Professor Tyndal, an authority of no mean weight in the field of experimental research, "it would be difficult to point to an experimental investigation conducted with greater sagacity, thoroughness, and skill, and which led to more important conclusions." It is this, supported as it is by like efforts and success in other departments, that entitles Sir Joseph Whitworth to a worthy place amongst the Heroes of Science.

When, however, his efforts were completed he was surprised at the attitude of indifference assumed by the Government. In 1859, a committee of officers decided that on the whole the Whitworth rifle was unsuited for introduction into the army. Some of the officers on the committee warmly insisted on the manifold and manifest excellences of the new weapon, but they were overruled, and the general verdict was against it. Very different was the judgment of the National Rifle

Association. In the year 1860 they opened a competition for the most perfect rifle that could be invented. The competition was open to all the world. The Whitworth rifle was pronounced the best, and was at once adopted. In the following year the competition was again opened, but the superiority of the Whitworth rifle was then allowed to pass without a challenge. These things did not move the English Government.

But there was at the head of affairs in France one who was keenly alive to the necessity of making the best preparations for the warlike emergencies which threaten the peace of empires. He had the spirit of the mechanician in affairs of state. By war comes glory, and his ambitions lay that way. The army was the great machine by means of which his object could be attained; arms were his tools; and he saw that to have the best and the best provided army would be to half win the battle before it was begun. The Emperor Napoleon, therefore, when he heard of the excellence of the new rifle, desired to have an interview with the inventor. Sir J. Whitworth had a long conversation with the Emperor on the subject at St. Cloud in October, 1860, and this was followed by a trial of his rifle at Vincennes, side by side with the best that France could bring. The results were so satisfactory that the Emperor at once ordered a number of rifles to be made for him, and commenced negotiations to purchase the patent for France.

Even in England the principles which distinguished the most effective rifle ever made could not be long ignored by the government or by the general public. In 1862, a Government committee declared that all rifles with any pretension to precision copied very closely the Whitworth pattern. At length, in 1874, the Government too adopted a design almost identical with it; but they called it by another name, and accorded the real inventor neither reward nor praise. The Martini-Henry rifle, then adopted, followed very nearly the pattern which Sir Joseph Whitworth had introduced after his series of costly and laborious labours. It had a seven-sided instead of a six-sided bore, and was substantially the same as the invention with regard to degree of twist in the rifling, and the proportion of length of bullet to diameter of section. It was a slight variation from the original form.

The experiments with rifles were followed by a series of expensive and herculean experiments with large guns; for the inventor thought that what had proved so useful on a comparatively small scale promised like success on a larger. The secret of success had been discovered in the one case, and he wisely inferred its more general importance. The new experiments were so expensive that it is astonishing that a private citizen should have undertaken them; so vast and various that it is astonishing he should have carried them through to success. He desired, however, to carry out a thorough investigation into the behaviour of projectiles from big guns, according to their twist and the length of projectile, similar to the complete experimental enquiries which had taught him how to make a rifle. He found that projectiles varying from one to seven diameters in length yielded the following results: "With one turn in ten inches, all projectiles went steadily with the point first; with one turn in twenty inches, the projectile became unsteady when more than six diameters; with one turn in thirty inches, it fell over when more than five diameters in length; with one turn in forty-five inches, the projectile turned over and flew very wild when more than three diameters in length. From these facts he concluded that unless a gun be rifled with a quick pitch, so as to give a high rotation to the projectile, it would not be possible to fire long projectiles."

In 1863, his guns were put to practical proof in actual war, and were much prized for their effectiveness, as shown by the experience of the American Confederate War. It was perhaps partly on this account that Government decided to compare the Whitworth and Armstrong guns in a series of experiments carried on the next year at Shoeburyness. The committee of experts declared themselves unable to decide which was the superior weapon; but it is remarkable that, while our Government would have no Whitworth guns, foreign governments would have no other; not a single Armstrong was exported.

Sir Joseph Whitworth continued his exertions with such success that in 1868 he was able to show a gun which could hurl a projectile of two and a quarter cwts. more than six miles.

Further experiments induced him to modify the shape of large projectiles. He was the first to show the importance of giving an easy outline to a body which had to fly at so high a speed through the air. It should be curved, as He who made birds rounded their bodies off, tapering them partially before and behind. In the case of a bird we see that the body tapers more behind than in front, where there is the broader expanse of the chest meeting the air; and Sir Joseph Whitworth proved, more by actual experiment than from analogy, that a similar shape was desirable in the case of projectiles. He therefore made them with a flattened instead of a pointed head, but discovered that it was very important that they should be made to taper off to the rear. A projectile so constructed carried a mile further in long ranges than one with the sides parallel all the way back. At short ranges no noticeable difference occurred.

The following is his own summary of his achievements in increasing the penetrating power of projectiles:—

"In 1857, I proved for the first time that a ship could be penetrated below the water-line by a flat-headed rifle projectile.

"In 1860, I penetrated for the first time a 4½ inch armour-plate with an 80 lb. flat-headed solid steel projectile.

"In 1862, I penetrated for the first time a 4-inch armour-plate with a 70 lb. flat-headed steel shell, which exploded in an oak box supporting the plate.

"In 1870, I penetrated with a 9-inch bore gun three 5-inch armour-plates, interlaminated with two 5-inch layers of concrete.

"In 1872, with my 9-pounder breech-loading gun and a flat-headed steel-projectile, I penetrated a 3-inch armour-plate at an angle of 45°.

"All these performances were the first of their kind, and were made, with one exception, with flat-headed steel projectiles, which alone are capable of penetrating armour-plates when impinging obliquely, and which alone can penetrate a ship below the water-line."

Long before he had pursued his investigations to this degree of success, he perceived one other field of inquiry opening to him, being led to it by the extraordinarily comprehensive view he took, embracing everything in any way related to the question which engaged his attention. He found the gun uncertain and not understood, he discovered its secrets and gave it precision. On the bullet or cannon-ball no one had thought it worth while to bestow much thought; he, however, showed that as much depended on its improvement as on that of the gun, and he gave it a new and terrible efficiency. He condemned the gunpowder which he found in use, and substituted a better quality for it; his cartridges increased the range fifteen or twenty per cent. But while busy with these invaluable improvements in ordnance, he also was impressed with the necessity of improving the metal of which it was made. The researches to which he thus turned his attention were carried on with the marvellous energy and perseverance, and were followed by the success, which distinguished all his efforts. It is on this account that he is ranked amongst the Creators of the Age of Steel, with Bessemer and Siemens. It was in this way that his great powers reverted to the service of peaceful industry, for his superior steel was as much needed to stimulate the arts of peace as to fulfil the requirements of war.

When he commenced his study of the rifle, Sir Joseph Whitworth found one of his chief difficulties in the inferior quality of the metal used for the barrels. Up to that time steel had been regarded as too brittle a material for guns, which were therefore made of iron. It was necesssary to improve the quality of steel before it could be employed for this purpose. The Whitworth steel which was at length produced was found as far superior to any material previously in use for guns, as his construction was an improvement on earlier forms. In 1871 a series of experiments was undertaken at the instance of the Brazil Government to compare the merits of Woolwich, Armstrong, and Whitworth guns. These three were declared to be all preferable to any manufactured in France or Germany, but the Whitworth gun headed the list, and its excellence was attributed as much to the character of the metal of which it was made as to the special features of its construction.

The Age of Steel is the name which has been aptly given to the period which dates from Sir Henry Bessemer's discovery of the process which is associated with his name. This makes the year 1856 an epoch in modern industrial history. That celebrated process was followed by new modes of treatment at the hands of Siemens, Whitworth, and others, all contributing to improve the quality of the metal or to facilitate its production. Sir William Siemens said, in 1869, that "a great revolution of our constructive art has been prepared by the production, in large quantities and at a moderate cost, of a material of more than twice the strength of iron; which, instead of being fibrous, has its full strength in every direction, and which can be modulated to every degree of ductility, approaching the hardness of diamond on the one hand, and the proverbial toughness of leather on the other." The result of the exertions of these master-workers was that this superior metal was produced at a cost little exceeding that of iron, and in such quantities as to meet a very rapid expansion in the demand. Steel, therefore, now finds an appropriate use for numberless purposes for which it was formerly unfitted on account of its qualities, even when it was not practically barred by its high price. Wonderful indeed have been the changes in the price of this metal, due to the progress of invention. Before the year 1750, the finest steel used in England came from India, and cost about £10,000 a ton. Then Huntsman, a clock-maker of Doncaster, who required steel springs for his watches, elaborated a process which reduced the cost to between £50 and £100 a ton; but even this was many times more than the price of iron. Sir Henry Bessemer introduced a simpler method. He poured the molten cast iron into a large vessel, called the converter, and forced a supply of atmospheric air beneath the surface of the fluid metal; this combined with the carbon contained in the iron, and burnt vigorously, creating great heat and consuming the carbon. His first successful experiment astonished as much as it gratified him.

"He constructed a circular vessel measuring three feet in diameter, and five feet in height, and capable of holding seven cwt. of iron; and he next ordered a small powerful air-engine and a quantity of crude iron to be put down on the premises in St. Pancras that he had hired for carrying on his experiments. . . . The primitive apparatus being ready, the engine was made to force streams of air under high pressure through the bottom of the vessel, which was lined with fire-clay, and the stoker was told to pour the metal, when it was sufficiently melted, in at the top of it. A cast-iron plate, one of those lids which commonly cover the coal-holes in the pavement—was hung over the converter; and all being got ready, the stoker, in some bewilderment, poured in the metal. Instantly, out came a volcanic eruption of such dazzling coruscations as had never been seen before. The dangling pot-lid dissolved in the gleaming volume of flame, and the chain by which it hung grew red and white as the various stages of the process were unfolded to the gaze of the wondering spectators. The air-cock to regulate the blast was beside the converting vessel, and no one dared to go near it, much less to deliberately shut it. In this dilemma, however, they were soon relieved by finding that the process of decarburisation or combustion had expended all its fury; and, most wonderful of all, the result was steel!"—W. T. Jeans: *Creators of the Age of Steel.*

The process was tried by other manufacturers, and turned out a failure. It chanced that the iron used in the first experiment was exceptionally free from phosphorus, an impurity frequently found in iron, and one which seriously damages its quality. After many attempts to eliminate this pernicious element, Sir Henry Bessemer fell back upon the use of a purer kind of iron which was naturally free from it. This he found could be obtained from the Dannemora mines in Sweden, at £7 a ton, and by blowing it a few moments in his converter, he could turn it into metal such as was then selling in Sheffield at £60 a ton. Steel requires some admixture of carbon with iron, and the Bessemer process at first burnt out too much of this necessary ingredient. The inventor remedied this evil by the use of a small quantity of ferro-manganese.

Sir William Siemens was the author of two processes, to which he was led by the previous invention of his regenerative gas furnace. In his earlier process iron ore is converted directly into steel on the open hearth, comparatively small quantities being melted successively in a bath of molten pig-iron in the gas furnace, and treated with ferro-manganese as required. In the second process he made use of a rotating furnace in which the ore was reduced to iron more quickly and easily than in the usual blast furnace. The balls of iron were then converted into steel as in the first process. This method of reducing iron from the ore was found to possess the advantage that it was applicable to the reduction of iron sand, rich in iron, but presented in such a form that it resists the action of the blast furnace or of other purifying agencies hitherto known. This iron sand exists in large quantities at various places, and by the Siemens process is rendered available for industrial purposes; it can withhold its treasures from man's use no longer. It was necessary to use qualities of iron low in phosphorus for the Siemens, as well as for the Bessemer process, until it was discovered by chance that, if a very intense heat is employed in the gas furnace, phosphorus is practically eliminated by the Siemens process.

Whilst Siemens was grappling with these difficulties in the production of steel, Sir Joseph Whitworth was also led to devote a share of his attention to the same subject, for the finest steel that he could buy fell short of the requirements of ordnance. He took a large ingot of the best Bessemer steel, and split it open. He found in the upper part of it innumerable small cells containing air or gas, which interfered with the soundness of the metal. There was a method of remedying this defect, but it involved the expensive and difficult task of pressing and rolling the solid metal. Sir Joseph Whitworth sought to find a simpler solution of the problem. During two or three years, from 1863 to 1865, notwithstanding the other absorbing researches in which he was at that time engaged, he conducted on an average some twenty important experiments a week with this object. These, too, were no easy matters; many of them were on a gigantic scale and involved more or less dangerous novelties in the treatment of the metal. Magnitude and novelty in an enterprise are the two qualities that make cowards of us all; but him apparently no magnitude of difficulty could appal, no novelty deter. He marched steadily through all obstructions to a worthy success at last. Like Stephenson, he made a level and a smooth road before himself wherever he would.

The object of his experiments was to apply the pressure to the molten metal so as to drive out all the gases before solidification takes place. He found that a pressure of six tons on every square inch of surface was necessary; that the larger the quantity of metal operated upon, the better were the results obtained; that it was most effectual to apply the pressure when the metal was in its most fluid state, immediately it was poured into the press. All these conditions added to the gigantic labour of his undertaking. He needed vessels of enormous strength to resist the enormous pressures which were required. The fact that the metal was to be fluid presented another difficulty; for, in order to apply pressure to it, it must be in a closed vessel, so that when the pressure is applied by the piston or plunger in one place the metal may not flow out in another; if, then, the fluid metal were thus trapped, how could the gases escape the same fate? Would they not also be retained? He found he could leave a space of one-tenth of an inch round the piston; when pressure was applied the molten metal rushed out of this narrow opening, but was immediately chilled and lost its fluidity. The remaining metal was therefore practically in a closed vessel. By providing a porous lining to the presses, he gave the gases a way of escape when driven out from the large volumes of molten steel under the vast pressures which he employed. It was found that not only were the gases expelled, but the steel itself was considerably reduced in bulk. The *compressed steel* which was thus produced was more ductile, more compact, and stronger than any previously made.

This new kind of steel was quickly employed, not only in the making of cannon, but also for many other purposes. Its advantages were conspicuous where, as in cases of locomotion, excessive bulk or weight of machinery was manifestly inconvenient. By the use of it the weight and cost of steel linings for marine cylinders, of cranks and propeller shafts, were materially reduced without any injury to their strength or durability, and thus many tons were saved for carrying purposes. The inventor proposes to reduce the deadweight of railway carriages from seven to five tons by the use of his steel instead of wrought iron, and estimates that this will in the lifetime of each carriage result in a saving of £600. For ordnance the superiority of the compressed steel was abundantly established. In connection with the experiments carried out on behalf of the Brazil Government in 1871, it was stated that a Krupp steel gun would last 600 or 800 shots; the Whitworth guns used by Brazil in the Paraguayan war fired from 3500 to 4000 shots each, without suffering any serious hurt. A gun barrel of compressed steel firmly plugged at the ends proved itself capable of enduring forty-eight explosions each of twenty-four ounces of gunpowder. A similar barrel of cast-iron burst into twenty pieces at the first discharge of three ounces.

Sir Joseph Whitworth wished to bring these results prominently to the notice of the British Government, and with the permission of the Brazil Government, for whom he had already made many of his breech-loading guns, he offered to lend them a 7-in. gun firing 33 lbs. of powder, together with a 35-ton muzzle-loading gun, capable of firing armourpiercing projectiles weighing more than half a ton. But both offers were declined.

Sir Joseph Whitworth took out a patent for his process in 1865, but four years more were spent before he could bring it into practical operation on a commercial scale. The patent would, therefore, have expired in 1879, but in consideration of the cost and usefulness of the invention the patent was extended for a term of five years by the Judicial Committee of the Privy Council.

The improvements that had been effected in modern artillery made it necessary to increase the power of resistance in defensive armour. Iron plates had been largely used, and were of course much less penetrable than wood, but against a Whitworth projectile they were both alike vain. Sir Joseph Whitworth considered the improvement of armour-plating a fit subject to engage his attention, and by his successes in dealing with it he rounded off a most remarkable and complete series of experiments and inventions dealing with every ramification of scientific artillery. The compressed steel proved well adapted to armour-plating. The plates which he designed were composed of six-sided pieces fitting accurately to one another. Each of these pieces consisted of concentric rings round a circular disc, so that, even if one ring were broken by the shock of a projectile, the crack would not extend to the neighbouring rings. The strength of this plating in comparison with the old iron-plating was marvellous. Against one such plate, nine inches thick, and supported by wooden backing and sand in the usual way, a Palliser shell, which would have passed through twelve inches of ordinary iron-plating, was projected from a distance of thirty yards. The shell was shivered into a thousand fragments; the steel plate was marked with a shallow impression by the blow, but was nowhere cracked. This demonstrated that the armour-plating of our ironclads might be made many times more effectual, and at the same time lighter, by the employment of these improved plates.

Strange as it may appear to one who has read the story of progress unfolded in these pages, and knows that the work of Watt, of Stephenson, of Whitworth, and of Nasmyth has been received as a welcome gift by all civilized nations, and that English invention is thus the impulse that has urged the world to advance in strides of rapid progress that make the conditions of life in the middle of last century seem remote indeed; yet it is true that at the time of the French Exhibition in 1867, England was being left behind by the chief continental nations; they had been advancing, England had been resting. In one respect the other nations of Europe were able to make steady advances all along the line, while England only rushed forward in obedience to the guidance of a few spirited leaders. They were the first to see the importance of advanced technical education, and they imparted it to all the managers and sub-officers, and in some cases very fully even to the workmen employed in their great mechanical concerns. Thus when the impulse was once given they were prepared to make the most of it. In England technical education on a large scale is only now beginning to be understood, and we have learnt the lesson from our neighbours. Thus all the work that was done was accomplished by a few giants in intellectual and practical ability, whose names are among the Heroes of Mechanical Science. The many went on as far as the road was smoothed for them by these, and then came to a stop. Anyhow the fact that England was perceptibly falling behind in the race was painfully evident to English mechanicians and men of science at the Paris Exhibition of 1867; and the alarming condition of things was by the consensus of the most clear-sighted observers ascribed to the want of provision for technical scientific education in this country, combined with the system of trades unions, in so far as these discouraged special skill and excellence on the part of any workman by withholding from him any special reward for displaying them.

Sir Lyon Playfair was one of the jurors at the Exhibition, and he brought the matter prominently before an educational commission, which was then sitting in London, by addressing to its chairman a letter on the subject. The importance of this communication was at once recognized, and copies of the letter were circulated for the purpose of eliciting the opinions of manufacturers and men of science. Whilst the public mind was still agitated at this revelation of national shortcoming, Sir Joseph Whitworth, in March, 1868, addressed a letter to Mr. Disraeli, the Prime Minister, in which he made the generous offer of £100,000 for the permanent endowment of thirty scholarships to be given by open competition, and to be held for three years under conditions calculated to encourage a closer relationship between the study of theoretical science and the practice of mechanical art. The munificent offer was gratefully accepted on behalf of the nation, and a well-deserved baronetcy was conferred upon the generous donor, who, seeing his country's need, was determined, though at great cost, to do so great a part in supplying it.

But the backwardness of England was attributed in some measure to the evil influences of trades unions. Sir Joseph Whitworth showed the right way to combat this serious evil also. In 1874 he turned his business into a limited liability company, in which the shares were almost exclusively reserved for those employed in some capacity in the concern. Further, he allowed workmen, who had not the means to purchase a share, the privilege of depositing any portion of their weekly wages to be employed with the capital of the company, and to receive interest at the same rate as that of the dividend on the shares. This excellent plan has since been followed by some other employers of labour. It gave the workmen a direct interest in the success of the concern. To combine against such employers, and to injure the business, would so clearly be a combination against themselves and result in their own loss, that such a course became impossible. Trades unionism, as a pressing evil, thereby lost its vital energy. It is an evil, however, which all masters have not learnt how to overcome.

Surely the record of Sir Joseph Whitworth's life shows an amazing deal of useful work for one man to have accomplished!

CHAPTER X.

CHARLES BABBAGE.

MORE than fifty years ago Thomas Carlyle saw and magnified the mechanical tendencies of the age, and pointed out how some cunning contrivance or other had been introduced to abbreviate almost every kind of human labour. We may now take even a fuller survey of the modes in which man can find an occupation for his powers, and we shall find that there is scarcely a region of human activity in which he cannot avail himself of the assistance of machinery.

On the physical side, the performance of work requires the exercise either of strength or of dexterity, generally one of these pre-eminently with the other as a subsidiary accompaniment; occasionally both occupy a position of equal importance in the work. A broad distinction, however, exists between the exercises of strength and the exercises of skill. When Adam delved and Eve span, or when their descendants first adopted this division of labour, the work of digging was carried on in the sweat of the brow, it required strength, and was relegated to the man; the process of spinning, which required less strength than dexterity, was assigned to the woman. Each of the two great divisions of labour, of which these are types, has, during the last hundred years, been brought more and more within the range of the power of machinery. First came James Watt, and revealed a more economical, manageable and effective mode of applying power than the exercise merely of brute strength, or than any other substitutes for it with which the world was at that time acquainted. Then, in the other province Arkwright, Crompton, and their successors have devised machines which display an unerring dexterity, passing the skill of woman. A machine that could accomplish the work of a few expert workers was developed, by the simple accretion of similar parts, until it could perform the work of a thousand; but this required an accumulation of force, and it was the steam-engine that rendered this development practicable. The continuous exercise of skill was, by the transcendent and well-directed skill of a few inventors, transformed into a trial of strength, and the same assistance was available as in other cases of the employment of great power.

Working in metal or in wood requires a combination of strength and dexterity; when this is (as it has been in many instances) made over to machinery specially designed for the purpose, it too becomes, so far as history at present goes, dependent on the grand mechanical idea first realized for us by the Scottish brass-smith.

If we push our inquiry still further, so as to embrace the operations of the mind, we find that these are of two kinds. Of the one, the processes of arithmetic, of which logical strictness is the essential characteristic, may be taken as an example. In the other, the mind indulges in all the liberty of imagination.

The strictly logical process is one that demands training and practice, and a consequent mental attainment analogous to manual dexterity; when this has been acquired, the mind proceeds, in the successive stages of its operation, as though it had no choice between two courses, as though the step it actually takes is in the direction of the only thoroughfare to thought. Arrived at this stage of acquaintance with a particular class of mental operations, such as those of addition or multiplication, the mind is often said to act mechanically; and a machine may, in fact, be made to exhibit the same unvarying sequence of operations in its progress from the proposal of the question to the one result; thus at once mental labour is saved, mental negligence is guarded against, and the work is reduced to one requiring physical strength. This is what Charles Babbage accomplished; but the world has not, up to the present time, used his calculating machine so extensively as to need the aid of Watt's economical and concentrated power in working it.

The imaginative processes of the mind would need for their representation a machine which would not lead to one particular desired result from a given starting point, but would surprise and delight us by the novelty of the results which it was unexpectedly producing. Such machine would, therefore, find but limited employment, and be less likely to become an object of utility than of amusement. We are not without even such a contrivance as this; witness the kaleidoscope of Sir David Brewster. Nor would machines of this sort be necessarily without a sphere of usefulness as aids to imagination, replacing some of the clumsier devices which are at times resorted to, and suggesting shapes such as we are apt to picture in cloud or flame. A painter of some repute last century is said to have been accustomed to shatter a lump of coal into a thousand pieces by dashing it on the ground, portraying the result upon his canvas as vast mountains and rocks peopled with the myriad creatures of his imagination, producing a weird and awe-inspiring scene, though possibly more terrible than natural. This was but a rude contrivance of his, but it constituted a machine for doing the work of imagination, for producing results which he accepted and used as though they were the product of his own imagination. More systematic aids to fancy may yet be contrived: nor should they be at once despised; for, "fancy shapes as fancy can," she is at all times dependent upon the actual, which she elaborates and transforms into a thing of greater beauty; a wider experience of beautiful forms as shown by a machine of this kind would be so much more food for fancy.

The great example of a machine designed to help man in his mental operations is the famous calculating engine. Although its inventor, Charles Babbage, preferred that men should know about his machine rather than about himself, yet in his autobiographical memoirs, entitled "Passages from the Life of a Philosopher," he has given some information about both, and to it we are chiefly indebted for what we know about his life. He was born on the 26th of December, 1792, and belonged to a Devonshire family of good position. Of worldly wealth he inherited enough to place him out of want, and to supply considerable funds for the expensive construction of his machine. Of the incidents in his early life which he mentions, one is specially noteworthy on account of its showing what manner of boy he was, and that a philosophical bent characterized his mind from a very early age. He was at school at Alphington, near Exeter, and whilst his schoolfellows were one day at play, he had gone to wander alone in the adjoining shrubbery, being prevented by a headache from joining in their sports. As he was leaning against a tree, and looking listlessly on the ground, he suddenly saw a bright yellow piece of metal. At once he forgot his headache, picked up the shining object, and carried it off to his schoolfellows, who all thought it must be some remarkable and valuable coin. The next day, on the authority of the village doctor, the supposed golden coin was, to the disappointment of all, pronounced to be a half-dram weight from the box of a pair of medical scales. The youthful philosopher, however, noticed the entire dissipation of his headache, and, in recounting the incident afterwards, says that it had an important effect upon his after life. He reflected upon the extraordinary fact that his headache had been completely cured by the discovery of the piece of brass. In process of time this principle took possession of his mind—*that occupation of the mind is such a source of pleasure that it can relieve even the pain of a headache;* and it gave an additional stimulus to him in many a difficult inquiry. His experience in after years was that a volume of "Don Quixote" or "Robinson Crusoe" could be relied upon to make him forget the pain of toothache, not of course in its acute form, but when it was tediously wearing. Although at first it required a painful effort to fix his attention, yet it almost always happened, after a time, that he forgot the moderate pain in the overpowering interest of the novel.

He was taken from time to time to see various exhibitions of machinery; amongst these was a collection of automata, belonging to a man named Merlin, which much fascinated the boy, and which he never forgot. It contained two female figures of silver, about twelve inches high, which would advance some four feet, turn round and come back to their former place, and perform graceful evolutions; this clever performance early excited his admiration of the capabilities of machinery. One of these silver ladies, after many years, came into his own possession, and served to entertain those of his visitors who could not comprehend the mysteries of his calculating engine.

From the school at Alphington he was transferred to another in the neighbourhood of London, where there were about thirty boys. One of his most vivid reminiscences was that of an unjust punishment which he suffered there. Adjoining the playground was an orchard belonging to the master; this had recently been robbed. One evening Babbage and another boy heard a noise there which they supposed to be a sign indicative of further depredations, and they valiantly determined to venture forth to the rescue of their master's property. On approaching the orchard they found that the supposed thieves were two of their own schoolfellows, who had gone out of bounds to get some manure for their flower-beds, and all four came back together. They were, however, seen by their master, who would not listen to any explanation or excuse, but fined them all indiscriminately for being out of bounds. Babbage was perhaps more unfortunate than disobedient in this well-meant transgression; the incident produced a painful impression on his mind, and after many years he wrote with some bitterness, "I never forgot that injustice."

These little stories would prepare us to find that he was a thinking boy. The school possessed a library of some three hundred volumes, which the little thinker used with interest and to considerable advantage. Amongst the books contained in it, his favourite was Ward's "Young Mathematician's Guide." His interest in this small treatise on algebra led him into the habit of getting up at three or four o'clock in the morning with a companion of like studious aims, lighting a fire in the schoolroom, and working there until five or half-past five o'clock. This second instance of well-intentioned disobedience to the regular discipline of the school remained for some months uninterrupted and unnoticed. Some of his schoolfellows, however, wanted to join the party, amongst them being Frederick Marryat, afterwards Captain Marryat, by which name he is now known to all schoolboys. There was a clever and for some time successful opposition to any increase in the ranks of this early working society, but at length further resistance proved vain; others of their schoolfellows joined them one by one, and instead of working they took to play; and when their amusement assumed the form of a display of fireworks in the playground in the early morning hours, they were discovered, and obliged to forego the liberty they had assumed.

From this school Babbage went to live with a clergyman in the neighbourhood of Cambridge, and pursued his studies with a view to entering the university. For a short interval before his entrance at Trinity College, Cambridge, he resided at Totnes, where he read classics with an Oxford tutor; but the whole bent of his mind was towards mathematics, which he read with avidity and enthusiasm. The interest which had been roused by Ward's "Young Mathematician's Guide" was permanent, and he made a rapid acquaintance with advanced mathematical methods, such as were then beyond the range of studies required by the university. He was able to employ the notations of Leibnitz, of Lagrange, and of Newton with equal facility in the solution of problems involving the principles of fluxions or the differential calculus, at a time when there was an insular prejudice at Cambridge against the introduction of foreign modes of analysis which ventured to rival those of Newton. Whilst thus pursuing the study of mathematics, he arrived at conclusions which appeared to him to be new, and was somewhat chagrined at discovering that they were well known. Instead of being altogether discouraged at these disappointments and giving up the hope of discovering something new, he was led on by the hope that when his knowledge became sufficiently extended and matured he really might contribute something to the discovery of new truths.

Thus prepared he had before him the promise of high academical distinction when, in the year 1811, he was entered at Trinity College. Full of ardent zeal, "anxious for aid, on knowledge bent," he turned to the chances which he fancied would be offered to him by the university; but he was disappointed by learning that a great part of the work of that body was in those days confined to a narrow, pedagogic groove, and that if he desired to expand beyond its limits, assistance was scarcely forthcoming. On his way to Cambridge he had made the costly purchase of the great work on the "Differential and Integral Calculus," by Lacroix, a long-coveted possession. This he commenced reading with care and attention, and when difficulties occurred he took them to his tutor and lecturers for explanation. Some told him that he would not want those difficult parts of the subject in his examination, and that he had therefore better not inquire further into them; others resorted to other means of concealing their mental indolence or their ignorance of the subject. Babbage was sharp-sighted enough to see through these various excuses, and he speedily became disgusted with the routine studies of a place whose teaching was so deficient in earnestness. Instead of going through the regular course, he immersed himself in the papers of Euler and other mathematicians, scattered throughout the volumes of "Transactions of Learned Societies," chiefly foreign; and his experience, thus gained, impressed him with the superiority of the notation of Leibnitz, which he set himself to introduce into Cambridge. With this object he founded the Analytical Society, composed of undergraduates with interests kindred to his own, amongst whom were Peacock and J. Herschel; a society strong enough to live down the scoffs with which alone the unsympathizing dons of that time condescended to notice it.

Babbage's intellectual sympathies were certainly very wide. He gave a fair share of his time to chemistry, and converted a spare room into a laboratory, in which he and Herschel carried on their labours together. They also both occasionally assisted Smithson Tennant, the professor of chemistry, in preparing his class experiments. He was an excellent and frequent chess-player, and took every opportunity of intercourse with others, especially with those of a philosophical turn of mind.

From time to time, by way of recreation, he took long trips down into the fens, of which he gives an amusing description. He had first of all to send his servant to the apothecary for "a thing called an 'ægrotat,'" which he understood, for he never saw one, meant a certificate that he was indisposed, and that it would be injurious to his health to attend chapel, hall, or lecture. This was forwarded to the college authorities, and release from these irksome duties followed as a matter of course. After five or six days of hard exercise in the open air, he and his companions returned with their health renovated, and were able once more to submit to college discipline.

To further the object of the founders of the Analytical Society, he set about the translation into English of the smaller work by Lacroix on the "Differential and Integral Calculus." This he finally completed in conjunction with Peacock and Herschel. He and his friends also thought it would be a wise movement towards winning the university over to their views, if they bribed the teachers and lecturers by preparing for them a collection of examples worked out in the method of Leibnitz; the saving of time and trouble by the use of such a publication would go far to ensure its adoption. This was, in fact, the result, and Babbage might well look with satisfaction upon the consequent emancipation of English mathematics from servitude to a particular system of symbols. Every new mathematical method is to the mathematician what a new tool is to the artisan,* and to ignore it in work where it is specially fitted to be useful is a sign of lethargy and of want of enterprise on the part of the worker, as well as an unwise rejection of valuable assistance. Yet the introduction of new mathematical methods generally requires at least as much determined perseverance as is needed for the success of newly invented tools. Babbage, as he himself said, had an inveterate habit of contriving tools. That his interest was not confined to the mechanical sort is proved by the movement in which he took so prominent a part whilst still an undergraduate at Cambridge.

But the chief interest of Babbage's life is that which centres in his celebrated calculating machine. The earliest idea of using machinery for the purpose

* "Without undervaluing the wonderful results which a Lagrange or Laplace educes by means of it, we may remark that their calculus, differential and integral, is little else than a more cunningly constructed arithmetical mill; where the factors put in are, as it were, ground into the true product under cover, and without other effort on our part than steady turning of the handle." (Carlyle, "The Signs of the Times.")

of calculating tables occurred to him in the year 1812 or 1813, during his undergraduate days. He thus records the manner of its occurrence :—

"One evening I was sitting in the rooms of the Analytical Society at Cambridge, my head leaning forward on the table in a kind of dreamy mood, with a table of logarithms lying open before me. Another member coming into the room, and seeing me half asleep, called out, 'Well, Babbage, what are you dreaming about?' to which I replied, 'I am thinking that all these tables' (pointing to the logarithms) 'might be calculated by machinery.'"

The idea lay dormant for a time; but after a few years the dream demonstrated that its fabric was not wholly baseless, by its partial realization in that portion of the celebrated machine which was completed by the inventor.

Babbage took his Bachelor's degree in 1814; he showed a disregard for the ordinary honours of the university by refusing to enter his name as a candidate for the mathematical tripos. His friend Herschel was senior wrangler; and Babbage regarded any other position than that of which he believed his friend to be sure as not worth striving for; he would not strive for any second prize.

The next year he became possessed of a house in Devonshire Street, Portland Place, London, where he resided for some twelve years. He was one of the original founders of the Royal Astronomical Society, which dates from the year 1820.

In 1816 he became a candidate for the professorship of mathematics at the East India College, Haileybury. He had strong recommendations, but he soon learnt that the chief merit to be considered in a candidate was interest with the directors, and this he was unable to claim. Three years later he became a candidate for the professorship of mathematics at Edinburgh; here he learnt that no qualifications in a candidate would compensate for his not being a Scot, and as he could not boast this recommendation he was rejected, notwithstanding testimonials in his favour from distinguished men like Lacroix, Biot, Laplace. Many other similar disappointments followed, and gave a tone of bitterness to his life which his subsequent experiences for the most part confirmed, notwithstanding that he had a fair share of honour and fame, and the friendship of illustrious men.

It was in the year 1819, after a conversation with Dr. Wollaston on the subject, that Babbage began to devise a machine for computing tables. The principle he adopted was that of successive additions, to be performed mechanically, in order to obtain the series of numbers required in the tables. Some years afterwards a gentleman addressed him thus: "Pray, Mr. Babbage, can you explain to me in two words what is the principle of this machine?" Mr. Babbage adds that, had the querist possessed a moderate acquaintance with mathematics, he might in four words have conveyed to him the required information by answering, "The method of differences."

The principle involved is one which is suggested by an examination of any series of numbers formed according to fixed rule, and can be understood by any one who has learnt to add and subtract. Let us multiply each of the natural numbers in succession by itself; we shall get a certain numerical table, namely, that of the square numbers :—

1 4 9 16 25 36.

If we write down the differences between each of these numbers and its successor, we have the numbers—

3 5 7 9 11,

which are called the first differences of the original series ; treating these in the same way, we obtain the second differences—

2 2 2 2

and these are seen to be constant, and would be found to be so, however many numbers in order are taken to start with. In the next line of differences, therefore, every term would be 0. By reversing the process we may find as many terms as we please of the series of square numbers simply by successive additions. If we know the first number in the line of first differences we obtain all the other numbers in that line by successive additions of 2 ; then, if we know the first number in the required series, we obtain the second, third, and all following numbers by adding to the last number known, or found, the corresponding term in the line of first differences.

Every numerical table is a series of numbers formed according to a general law, and if the first, second, and successive differences are found, we shall at length reach a line of differences where the terms are all equal to one another, either for the whole of the series, or at least for a long succession of terms. When this common difference is known, the various lines of difference may be written down, beginning at the last of them, if the first number in each is known. In the example given above we have found the successive differences from the numbers themselves; but they can be discovered from a knowledge of the law of formation of the numbers. When this has been done the calculation of the tables is carried on by an almost mechanical repetition of the simple process of addition; it requires no genius, any one can do it who has been shown the way and knows how to add, and the less he thinks about the meaning of these columns of differences, the less will he be distracted from the work in hand, and the better will he perform it. Babbage saw that these operations were within the powers of machinery, and he followed up this insight by the invention of suitable contrivances, whereby his engine could, in the first place, add; in the second place, add the successive differences in turn, without constant attention on the part of a superintendent; and in the third place, print off its results, and thus avoid the chances of error due to imperfect copying. The calculating machine was designed to effect this work in the vast number of cases where the terms in the seventh line of differences might all be taken as zero.

It may seem that a machine of service only for the purpose of computing numerical tables, and not for performing any casual calculation that might be required, would be of slight practical value, and that the trouble and expense bestowed upon it would exceed any possible advantage it could offer to the world. But the field of labour thus reserved is vaster and more important than is generally imagined. The number, extent, and variety of numerical tables that have been calculated, and found useful, and still more of those that would be useful if only the task of computation were undertaken, are so great that it is not easy to convey an idea of their magnitude to readers who are acquainted with nothing beyond tables of logarithms. We begin our acquaintance with numerical tables at an early age, namely, when we begin arithmetic; such tables are retained in the memory for ready use, but ordinarily no great advance is made in the use of tables for reference. There are purely arithmetical tables of multiplication, of different powers and roots of numbers. There are geometrical and trigonometrical tables, giving functions, complex and simple, of angular, linear, superficial, and solid magnitudes; such have been published in all countries for the benefit of surveyors, architects, builders, carpenters, miners, engineers. There are the universally useful logarithmic tables; beyond these there are tables of interest, exchange, annuities, and other tables needed by life insurance offices; but in astronomy and navigation such tables are very numerous and necessary. To determine the exact place of a ship at sea is a task of the highest importance for its safety. This may be best accomplished by accurate observations of the apparent position of the moon relatively to the stars which are near to it. The moon is near enough to the earth to appear to occupy at any instant different positions against the background of the stars, when viewed from different places on the earth; if the apparent position of the moon is noted, and also the exact time, then the position of the place of observation can be determined. The method is the result of much astronomical study, but it is necessary to adapt it for use by rule of thumb, for the meaning of it is beyond the comprehension of the majority of mariners; and, besides, the process itself is too long and cumbersome for daily use, if all the calculations need to be effected afresh in every instance. Subsidiary calculations for all possible cases are therefore previously effected, and tabulated in the "Nautical Almanac" for immediate use by seamen. In order to make use of the lunar distances from any one fixed star, not less than ten numerical tables peculiar to that star are required; a thousand such tables are actually published, but it would require ten times as many to bring into the service of the navigator all the bright stars that lie directly in the path of the moon, and a much greater number to include those near which the moon passes, which might similarly be utilized. The positions of Jupiter and Saturn are similarly useful, but not so to the mariner until not less than 116 tables have been prepared for each of these planets. The object of numerical tables is not only to save the labour of computing on the part of those who use them, but also to ensure accuracy in the results; for the human computer is a calculating machine that cannot be trusted to work with uniform infallibility, however careful or experienced he may be. The chance of error in the result is diminished by the use of tables published by competent authority; but even in such tables, however carefully prepared, errors are found; and the only escape from them is to provide for the mechanical calculation and printing of the tables; for a machine need not be subject to the universal human liability to err. At the same time, the construction of such a machine would facilitate the production of tables, and many more would be introduced into general use; for in the multitude of tables of reliable accuracy there is safety for all who have much numerical calculation to do.

From the explanation already given, it will be clear that all tables may be calculated by a machine that can perform the arithmetical operation of addition. This is not the place in which to offer any explanation of the necessarily complicated contrivances to which Babbage resorted in constructing his Difference Engine No. 1, as he called the first of these machines on which he occupied himself, and the only one which actually assumed a real shape. It will be enough to refer for this information to "Passages from the Life of a Philosopher," by Charles Babbage, M.A., and to an article in the *Edinburgh Review* for July, 1834, written by Dr. Lardner. It is a less difficult task to give an account of the history of the engine, of the obstacles which lay in the way of its completion and finally proved insurmountable. Having made a small model, capable of working two orders of differences on the principles which he thought might with advantage be employed in a larger machine, he addressed a letter, in the year 1822, to Sir Humphry Davy, President of the Royal Society, in which he explained his views on the subject, but intimated that he hesitated to continue his labours in the same direction by the construction of a larger and necessarily expensive engine, unless he received some public encouragement to prosecute the undertaking for the public good. The Lords of the Treasury referred this letter to the Royal Society, who, in 1823, reported in favour of a grant to Mr. Babbage for carrying on the work. In July of the same year Mr. Babbage had an interview with the Chancellor of the Exchequer, the result of which was the advance of £1500. Mr. Babbage was under the impression that the engine when completed would belong to Government, who would meet all the expenses incurred in its construction; but no minute of the conversation was kept, and successive

Governments for a long time assumed that the grant was merely a subsidy to an ingenious inventor to enable him to perfect a pet hobby, which might possibly be useful to the country when completed. From this time for four years the construction of the difference engine proceeded, at an expense of £3475, the work being placed in the hands of the distinguished mechanical engineer, Joseph Clement. Mr. Babbage was then obliged by the state of his health to travel on the continent, but he made arrangements for the continuation of the work according to his plans during his absence. It was now clear that the expense was greater than he had anticipated, and he thought it right to communicate this information, and to report progress to the Government, whom he regarded as his employers in the undertaking.

Whilst still in Italy, he received, in 1828, the unexpected news of his election to the Lucasian Professorship of Mathematics at Cambridge, the chair which had been held and honoured by Newton. He was at first averse to accepting this honour, lest the accompanying duties should interfere with his development of the calculating engine, to which he was now anxious to devote all his time; but he followed the advice of the friends who were near enough to be consulted, and resolved to accept the chair of Newton at least temporarily.

In consequence of his communication with Government, the Duke of Wellington referred the matter to the Royal Society for their opinion, and in consequence of their report a further grant of £1500 was made, but by that time the sum expended on the engine had amounted to £6628, and an influential representation was made to Government for a grant of further funds. This led to an offer of a further sum of £3000; but Mr. Babbage, before accepting it, thought it right to have any misunderstanding that there might be with regard to the relations between the Government and himself finally cleared up. He urged the following three requests:—

1. That the engine should be considered as the property of Government.

2. That professional engineers should be appointed by Government to examine the charges made for the work already executed, as well as for its future progress; and that such charges should be defrayed by Government.

3. That he himself should continue to direct the construction of the engine as he had hitherto done.

He maintained that he had not commenced the machine on his own account, but had offered to construct one for Government, if they were sufficiently impressed with its usefulness to engage him upon the work. Mr. Goulburn, the Chancellor of the Exchequer, on the contrary, seemed to regard Mr. Babbage as an applicant for aid to rescue him from difficulties, which he had encountered in an imprudent and too zealous pursuit of a pet scheme of his own. The delay that followed, and the indifference manifested towards his labours and many sacrifices, gave him opportunity and some cause to think about his grievances. He insisted strongly that he had been engaged to accomplish a work which the nation desired to have done, and that his own interest in its completion was dependent on that which they exhibited. So far as his own invention was concerned he was convinced of its feasibility and utility, without the material presentation of it in a tangible form. Not to satisfy himself, not to test the value of the contrivance, but solely to confer a favour on the nation, had he undertaken the long task, and this on the understanding that he should not in the end be pecuniarily a great loser. When he found that public support was not forthcoming, and that the burden of a great expense was put upon himself, as though he would necessarily be so fascinated with the machine as to give his all, if need be, in order to finish it, then he began to grow slack in his self-sacrifice, and to oppose indifference to indifference. Difficulties at the same time arose with the engineer who had been constructing the engine under his direction, and these were aggravated by the embarrassment in which Mr. Babbage found himself through the delay of Government. At length, in February, 1830, the Government announced that they were willing to declare the machine their property, and to grant another £3000 (making £9000 in all); they would not, however, pledge themselves to complete the machine, but if it should be completed they would attend to any claim that Mr. Babbage might make for remuneration.

When matters were placed upon this intelligible footing, the reconstruction of the machine was resumed. For the safety of the part already completed, and of the valuable drawings which contained the result of long and laborious thought, a fireproof building and workshops necessary for the completion of the work were built on some property adjoining Mr. Babbage's residence, the lease of which had been granted him by Government.

In the year 1833, another obstacle presented itself, and ultimately led to the abandonment of the work. Mr. Babbage had directed a portion of the engine, capable of calculating tables having two or three orders of difference, to be put together. This was done, and the result was most encouraging. He now, however, found it inconvenient to continue to make payments to the engineer in advance of the sanction of the bills and the grants from the Treasury, and the engineer at once discontinued the construction of the engine, and dismissed all the workmen employed on it. These facts Mr. Babbage communicated to the Treasury, and asked for instructions. There was a delay of a year and a half before authority was given to resume the work, and meantime Mr. Babbage, in his speculations on the subject, hit upon an entirely new principle, which promised far better results than any that he could hope from the difference engine. This he took as the basis of a machine, which he afterwards fully planned, and named the Analytical Engine. This new machine was to consist of a much greater number of parts than the first, and in fact its construction would be wholly impracticable, on account of its complexity, unless the methods of mechanical addition, which he had adopted, could be considerably simplified. He was thus led to devise important simplifications in the original machine, which superseded his past work upon it. All these discoveries, as in duty bound, he communicated to Government, and asked whether under these circumstances they desired him to continue his engagement with them for the difference engine. This was the death-blow to the engine. The Government looked upon his communication as an application for assistance in constructing another and a more complicated machine, from which, however, Mr. Babbage had been careful to guard himself. They therefore took a long time to consider the matter, and the delay was increased by successive changes of Governments, and by the pressing political questions of the time. The delay was resented by Mr. Babbage as an unnecessary suspense, seeing that his question could easily have been answered with a yea or a nay, and he professed to want no more than some such definite answer. In November, 1842, after eight years of irksome waiting and many importunate communications with various ministers, Mr. Babbage was informed that Government did not feel themselves justified in incurring the expense which would be necessary to make the invention satisfactory to Mr. Babbage or generally useful; they, however, withdrew all claim to the machine as already constructed, and placed it entirely at his disposal. This offer he declined to accept, and the portion of the machine at that time constructed, together with all the drawings relating to the invention, were deposited by the direction of Government in the Museum of King's College, London.

From this time Mr. Babbage was engaged in mastering the ideas which had suggested themselves to him for the construction of the analytical engine; and in doing so he made complete plans for modifying and simplifying the difference engine by taking advantage of the new inventions which necessity obliged him to devise for the more complicated machine. In 1852 the Earl of Rosse suggested that Mr. Babbage should make an offer to Government to construct this improved variety of his engine, if the Institution of Civil Engineers should report favourably upon the possibility of its completion according to the plans carefully drawn, and if they could give an estimate of its cost which would not be prohibitive. The question had, indeed, been once disposed of, but meantime advances had been made in mechanical engineering; tools and the skilled labour for the purpose were more easily obtainable, and it was probable that persons might be found willing to undertake the construction, according to the plans, at a fixed cost. Mr. Babbage consented to make this application to Lord Derby, whereby he looked upon himself as discharging to the utmost limit every implied obligation in his original contract with the country. Lord Derby referred the matter to Mr. Disraeli, who was his Chancellor of the Exchequer, and who does not appear to have given much attention to the subject; for, without consulting the Institute of Civil Engineers, as was proposed, he decided on his own authority that the project was indefinitely expensive, and the ultimate success problematical, and that Government would not be justified in taking upon itself any further liability. This unwise utterance on the part of one who had not studied the question, and who, notwithstanding his great abilities, was not himself qualified to understand it, destroyed all hope of the embodiment of Mr. Babbage's invention in a practical form. "Science was weighed against gold by a new standard, and it was resolved to proceed no further." The cost to Government so far had been £17,000, but the expense to Mr. Babbage had been actually greater than this. In addition to these expenses he had made other sacrifices, for he had declined several offers of great personal advantage in order to devote his attention the more completely to the calculating machinery. A few years afterwards the very plan rejected by Lord Derby was adopted by another administration in the case of a similar machine, called the Swedish Difference Engine, for which employment was at once found in the department of the Registrar General, at Somerset House. This machine, in Mr. Babbage's opinion, presented far greater mechanical difficulties than his own, the drawings of which he had offered to Government; and it gave him an additional sense of wrong endured to find his work thus ignored.

Thus an invention designed to hand over to inanimate metal a part of the laborious mental work of man, attained at best but a very imperfect success. So much was completed that the adequacy of the principle of the earlier machine to its purpose was fully demonstrated. But the construction of it was a gigantic and costly undertaking, and its parts, as Mr. Babbage afterwards showed, unnecessarily complicated. The delays were therefore fortunate, and the final discontinuance wise; the work done was not in vain—it offered the only preparation to the more perfect idea which succeeded it in the inventor's mind. But the Government were then not disposed to take in hand another scheme of the same author's, when they found that they had contributed £17,000 to one which he had relinquished before completing it. The cost of construction had been not only great but also apparently excessive, and Mr. Babbage ascribed the fate of the "unfortunate invention" to the extravagant demands of the engineer. No doubt this had some effect in prejudicing the Government against giving further aid in these costly experiments; but the fatal cause of failure must be sought elsewhere, and it is found in the position which Mr. Babbage himself took up. He never professed to be anxious to construct the machine on his own account; he had perfectly invented it on paper, as his elaborate drawings showed. He was so convinced of its importance that, cost what it may, he thought its construction ought to be ordered. He did not perceive the same belief in its usefulness on the part of others, and was therefore indignant with them for their deficient interest in it. If the nation would but rise to its duty, he was willing to labour for them as their servant, but as they would reap the benefit they ought to initiate the work. But the public had neither sense of its needfulness nor confidence in its success to make them eager to have the machine made, although it excited their curiosity not a little. Unfortunately, Mr. Babbage was too much of a philosopher to be enough of an enthusiast. Had he simply determined that the machine should be made, and proceeded with the determination of a Watt or even a Crompton, he might have carried one if not both of his engines through to a successful issue; and there is little doubt that when he had shown his machine in working order he would have had compensation at least for his outlay upon it; both his fame and his works would be in higher estimation than they are now, for the world which credits what is done is cold to all that might have been. Perhaps he gave more than the world had any right to expect, in the sacrifice of time and money, but the foremost and most honoured benefactors of the world have been accustomed to bestow their "gifts beyond measure;" and hence, while we acknowledge that we owe much to Charles Babbage for his ingenuity, we feel that he failed to do all that he might have done to bring his invention to complete success. He had a real grievance in that his self-sacrifice, though limited by prudential considerations, was not sufficiently recognized. He was not great enough to check his mortification, and cheerfully to persist in his undertaking. It would be unfair to say that he was not disinterested; but he was too conscious of his disinterestedness, and dwelt upon it to the injury of the work he had in hand. He thus fell short of the rare greatness which ensures success and wins universal admiration.

Although the calculating engine failed practically to extend the application of machinery to the calculation of tables, yet it showed the way. As a contribution to science it was a success, perhaps the chief amongst many that were due to Mr. Babbage. Unfortunately, the story of others of his scientific advances is also largely a story of grievances.

In the year 1824, soon after the commencement of the first engine, the Astronomical Society conferred upon Mr. Babbage the first gold medal they ever bestowed. The president in his address on that occasion foreshadowed the possibilities to which the new invention might lead. These imaginings were afterwards fully confirmed; for when the analytical engine had advanced to some completeness in its author's mind, and had been embodied in his numerous plans and drawings, he was able to demonstrate that the whole of the developments and operations of analysis were capable of being executed by machinery, and that there was in consequence no reason why mental as well as bodily labour should not be economized by its aid. He left behind him every assistance to enable any one, upon whom his cloak may fall, to understand the exact position of the subject as he left it, and to avail himself of the advances which he made.

Having gained the first gold medal of the Astronomical Society, he thought that the first royal medal to be awarded by the Royal Society might well become an object of ambition. The council of the society resolved that the two gold medals of fifty guineas each, which had been founded by King William IV., should be awarded for the most important discoveries or series of investigations completed and made known to the Royal Society in the year preceding the day of award. In order to qualify himself for this, Babbage drew up a paper "On a method of expressing by signs the action of machinery," which was read at a meeting of the Royal Society on the 16th of March, 1826. This system of signs was the *mechanical notation*, to the invention of which he attributed the possibility of developing the complicated machinery of the analytical engine, and of rendering it intelligible to others; it also simplified the explanation of all kinds of machinery. Mr. Babbage was disappointed and indignant that the two medals were not awarded according to the conditions announced; they were given for papers published in the "Transactions," in one case three years, and in the other case twenty years, before the day of award.

Whilst Mr. Babbage, in these and other instances, received scant recognition at the hands of his countrymen, he was consoled by the reflection that foreigners treated him with greater honour, and were much impressed with his achievements. He was received with marked cordiality by Charles Albert, King of Italy, on his visit to Turin in 1840, to attend a scientific congress, and was indebted to his Majesty for the first public and official acknowledgment of his invention. He tells how that one day he met Count Strzelecki at the house of a friend, and many inquiries were made relative to the Count's residence in China. He informed the company that the subject of most frequent inquiry was Babbage's calculating engine, and mentioned that the Chinese were most anxious to know whether it would go into the pocket; whereupon Babbage remarked that the Count might safely inform his celestial friends that it was in every sense of the word an out-of-pocket machine. Mr. Babbage did not surrender himself entirely to the melancholy which was caused by his disappointments; he insisted upon his grievances because he thought this was demanded by justice, but even in his bitterest complaints he would allow a touch of humour to qualify his bitterness.

Of his publications, "Reflections on the Decline of Science in England" appeared in 1830, and was occasioned by his own unfavourable impressions of the condition of science at the time. Two years later his "Economy of Manufactures and Machinery" was published. To the worth of this treatise he received one of the highest testimonials on the occasion of a short visit to Bradford. Having met an intelligent working man, and acquired information from him on many subjects, he thought it possible he might have read that work. He found he was well acquainted with it, and asked Mr. Babbage what he thought of its merits. When he heard that he was speaking to the author of it, his delight was unbounded, and he afforded great gratification by observing, amongst other things, "Sir, that book made me think;" to which Babbage adds, that to make a man think is doing him far higher service than giving him much instruction.

In 1837 appeared the Ninth Bridgewater Treatise; of this Charles Babbage was the author. It contained his own novel views on the nature of miracles and of prophecy, which were accepted by many men of very different religious opinions. He showed that the difference engine could print a numerical table according to some law, dependent upon the construction of the machine, which, after coinciding with that of successive integers for a long time, should suddenly change to some other series apparently unconnected with the first, and then as suddenly revert to the same simple succession. He maintained that if he could so construct a machine, the Deity could have framed the universe so as to allow divergencies from the uniform sequence of events which we call nature, and that these divergences are miracles.

Mr. Babbage was interested in puzzles of all kinds; the picking of locks and the deciphering of ciphers occupied a great deal of his attention. He at one time wrote a paper, which however he did not publish, "On the Art of Opening Locks," at the conclusion of which he proposed a new plan for partially defeating his own method. This plan was founded upon the same principle as that for which Mr. Hobbs afterwards took out a patent.

In the year 1829 Mr. Cavendish, afterwards Duke of Devonshire and Chancellor of the University of Cambridge, was a candidate for the representation of that university in Parliament. Mr. Babbage was the chairman of his committee, and brought to bear energy, enthusiasm, and ingenuity, that contributed greatly to the success of the election. After the Reform Bill was passed in 1832, Mr. Babbage again became chairman of Mr. Cavendish's committee. Mr. Cavendish and the other Liberal candidate, Lord Palmerston, were both defeated on that occasion. The excitement of an election generally leaves behind it a legacy of stories. Amongst those of the Cambridge election is that of an amusing squib which originated in Mr. Cavendish's committee room, and probably in his chairman's humorous brain. Mr. Goulburn was one of the Tory candidates. Late one evening a cab drove up to the office of the *Morning Post*, and delivered a copy of the following paragraph, purporting to come from Mr. Goulburn's committee, at the same time ordering fifty extra copies of the paper to be sent next morning to their committee room. Accordingly the paragraph was inserted as follows:—

"The Whigs lay great stress on the academical distinction attained by Mr. Cavendish. Mr. Goulburn, it is true, was not a candidate for university honours; but his scientific attainments are by no means insignificant. He has succeeded in the exact rectification of a circular arc; and he has likewise discovered the equation of the lunar caustic, a problem likely to prove of great value in nautical astronomy."

By the satisfied way in which Mr. Babbage refers to this electioneering joke, he confirms the internal evidence it affords, and writes himself down as the originator of it.

He was himself a candidate for the borough of Finsbury in 1835, but was defeated, and did not again seek to enter Parliament. He announces his defeat with philosophical composure, and adds that he was not particularly desirous of wasting his time for the benefit of his country, and, with a touch of satirical humour, he closes the narrative by saying, "The constituency of Finsbury had already expressed their opinion that Mr. Wakley and Mr. Thomas Duncombe were fitter than myself to represent them in Parliament, and in that decision I most cordially concurred."

It was during Mr. Babbage's life that the railway was conceived and brought to a practical success. He naturally took a great interest in it from the beginning. He was present at the opening of the Manchester and Liverpool railway, a great event saddened by the fatal accident to Mr. Huskisson. He suggested many contrivances for diminishing the dangers of the new mode of travelling, but these were not very eagerly adopted by the directors of companies. On one occasion he was seated at dinner next to an eminent London banker, who expressed disapproval of the railway: "Ah!" said he, "it will enable our clerks to plunder us, and then be off to Liverpool, on their way to America, at the rate of twenty miles an hour." Mr. Babbage replied that science might perhaps remedy the evil, and that possibly we might send lightning to outstrip the culprit's arrival at Liverpool, and thus render the railroad a sure means of arresting the thief. It is noticeable how progress invariably rouses fears, and how new remedies are always available for the new evils; the evil itself does not always seem so formidable when it is really met, and proves but a slight drawback to the accompanying good.

On the construction of the Great Western Railway, Mr. Babbage had something to do with the introduction of the broad gauge. He was requested by Mr. Brunel and the directors to report to them upon the question. After a series of experiments he became convinced that the broad gauge was the most convenient and safest for the public. At the general meeting of the shareholders he made a statement of his views, and considerably influenced the decision arrived at. Some years after he met a Liverpool gentleman who was at the meeting, who told him that he had come up with other proprietors holding several thousand proxies, and prepared to vote according to the weight of the arguments adduced. It was Mr. Babbage's statement that determined them in favour of the broad gauge, and he added that but for that speech the broad gauge would never have existed in England.

Mr. Babbage was once conversing with Sydney Smith, who urged him to make a representation to Government on the dangers of railway travelling and the means of remedying them. He answered that such a mission would be useless, and that nothing would be done until some great man were killed in an accident; "perhaps a bishop or two would do," he said, "for you know they are so much better prepared for the change than we are."

Towards the close of his life Mr. Babbage attained a notoriety that was not fame, by the vigorous measures he took to put down street nuisances. His object was a good one, but it made him the butt of much ridicule, to which even the pages of *Punch* bear testimony. He spared neither expense nor personal trouble in endeavouring to abolish organ-grinders; during one twelvemonth he spent about £104 in this herculean task. Thinking probably of the gibes with which his well-meant efforts had been received, he remarks triumphantly, as though the public had been unconsciously but duly punished for their unsympathizing levity by some incalculable loss, that he was not himself the only sufferer; that amount would otherwise have been expended in giving a year's employment to a skilled workman, whose wages are about £2 a week.

Thus we take leave of Charles Babbage, a man of extraordinary ingenuity, and deeply interested in anything ingenious, whether mechanical, philosophical, or purely fanciful; he was always occupied with some new problem or some new theorem, busied with the attempt to make some new thing, or to prove some newly apprehended truth. He liked to trace appearances back to those antecedent phenomena which we call causes, but which declare in what way, and not for what reason, event follows event. He was intensely logical, and if he saw men ignoring some fact which he thought they ought to recognize, he never grew weary of urging it upon their attention. His great work would more probably have been successful had he been able to concentrate upon his calculating machinery the interest which wandered to all the realm of thought, and especially if he had not harboured the notion that the neglect of his labours and indifference to the benefits which they promised were a grievous and unpardonable injury, to be much brooded over and resented. His resentment, whether against chancellors of the exchequer or organ-grinders, was not, however, very fiery; in the midst of it all he maintained a calm philosophical otherself, which could indulge in humorous reflections when he felt most hardly treated.

He died at his residence in Dorset Street, in October, 1871, in his eightieth year.

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