THE HISTORICAL DEVELOPMENT OF SCIENCE.

I.—Heat.

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Although, like many lower forms of life, we could live and have lived without any *understanding* of the nature of heat, without any idea as to how to control or how to employ it, yet the advance of civilisation can be traced along the lines of our gradual acquirement of the knowledge of how to utilise available heat energy.

All the heat we use comes from the sun. Glancing briefly at our storehouse of heat, it will be interesting, since this is an historical study, to go back to the very beginning of our earth. Some two thousand million years ago, for reasons into which we need not enquire here, our earth, accompanied by a number of brothers and sisters (the planets) and a vast host of unimportant cousins (the asteroids) left the sun and shortly afterwards settled down and set up home in a highly desirable and convenient orbit in which we now move round the sun. We brought with us a big supply of heat energy, which we dissipated at a really alarming rate until we established a surface crust which acted as a blanket to the rest of the contained heat energy, so that it now escapes but extremely slowly from the intensely hot material below the crust. So extremely slowly, in fact, that if we depended on it alone for warmth we could not possibly exist, and the whole world surface would sink back to a state of incredible cold. There is one other local immediate supply of heat—the radioactive materials in the surface layers of the earth's crust, which give off heat energy as they break down into less complex atoms. This source of energy also is negligible as a supply for us. All our immediate supplies of heat energy come as radiations from the sun—the earth warming up whilst the sun shines, and radiating most of that energy away again into space. The waste here is incredible; if the solar energy were completely cut off from the earth for a few days, life would be impossible.

We are not able to make use of this energy directly. It would not be at all satisfactory to sit out in the sun instead of having dinner; and the wearing of a backless costume would not have the effect of an extra good meal. But plant life has this ability, and we, dependent on the sun, are directly dependent on plants to trap the energy for us. If plant life had not evolved upon the earth, if our world had remained entirely unclothed by vegetation, then the energy coming from the sun would regularly have been thrown back into space again, none being stored. The plant, however, is able to trap some of the solar energy that falls upon it, and by that means build up from the chemicals in the earth's crust some materials which can be again burnt or oxidised in the air, thus to give off the stored solar energy. The most important of these materials are carbohydrates (such as starches and sugars), hydrocarbons (oils), plant proteins, and cellulose.

We are engines, working by taking on and burning up these materials ; that is, we make use of some small part of the recently obtained solar energy. Even then humans cannot utilise what forms the bulk of the plant fuel—cellulose. But a ruminant animal such as a cow will do that for us—minute organisms in the animal's stomach convert the cellulose to carbohydrates, which she then utilises, and we then utilise the cow.

If plants and animals could think, I wonder whether they would consider us vastly clever and superior beings, or merely unpleasant parasites who are quite incapable of doing things for ourselves, and make use of the skill of so-called lower organisms ?

For a very long time after plant life came there were no animals to eat the plants and no humans to eat both animals and plants. Then later came animals to help themselves to the plants. Plants grew prolifically during the hot-house period of the earth, and dying and being buried, were stored up with the energy they had obtained from the sun's radiation. Of the big stores of energy daily received the most was even during that period reflected and radiated out into space again ; some was otherwise wasted ; and a small portion was banked each day, to be apparent to us now in the form of peats, coal and oil. This was put down in the safe deposit vaults of nature's banks, and did not bear interest on the stored energy—that was not possible. At times thieves in the form of volcanic disturbances broke in and big stocks of fuel were burnt, the energy being sent out into space again.

We can either consider ourselves as thieves of a later generation or say that it is our property and all stored for us, whichever appeals more to our sense of importance ; and the greater part of the science of physics with regard to heat and the applied physics of heat engineering has concerned itself with the utilisation of this solar radiation energy stored in nature's vaults.

We still consume great quantities of contemporary radiation—we eat present day vegetation and animals, and not coal or mineral oil, and we burn wood when we can get it conveniently and cheaply. I do not think that there is any doubt that our earliest ancestors to control and utilise fire were concerned with the vegetation of their day, and that petty thieving of the prehistoric stores began at a much later date. Man must have gone in great fear from the raging forest fires, and showed his great difference from co-existent animals when first he took it and kept it under control for his own protection and comfort. Protection, from savage animals who feared the fire ; comfort, from the warmth and cheerfulness of a controlled menace. Later he developed fire brands and torches for light. We do not know when first he used fire to alter the chemical nature of the animals he consumed—Lamb's tale of the Roast Pig is not intended to be historical, though it is probable that the first cooked food was an accident, as much of it still appears to be today.

Although physics was not properly established as the experimental science until the 17th century, it was not entirely observational previously, since even the earliest steps in the utilisation of heat must have been a matter of experiment. The man deliberately altered ordinary conditions to see what happened then. After fire was controlled to give warmth, light and protection, and to prepare food, the next advances were to make it do other useful work. The history of the development of thermodynamics, as that Section of Physics is called, is one of the attempts to get as much useful mechanical work done as possible for a minimum expenditure of fuel and of human control.

The first historical references to heat engines are contained in a publication by Heron of Alexandria, in the second century B.C. The devices he mentions are mainly toys, but two of the engines are typical of much later inventions. One of these was a steam reaction turbine, generally referred to now as "Heron's engine". A hollow metal sphere was supported and pivoted so as to be able to spin about a diameter, and steam was admitted to it by one of the hollow supports and pivot ; the steam then escaped by a couple of pipes facing in opposite directions at the ends of another diameter. The reaction caused by the escaping steam makes the sphere revolve on its pivots. You have seen this principle applied in the ordinary revolving type garden sprinkler. The reaction principle is employed in the new rocket aeroplanes and rocket cars, which are still in the early experimental stages, and is also employed with certain types of steam turbines. It is also, of course, the principle of the simple sky rocket.

We do not know how this principle was originally discovered, but this clearly was an actual experiment which Heron made, and not merely a speculation. Another ingenious heat engine which he describes is one for opening temple doors. The altar is hollow and connected by a pipe with a large closed vessel in the cellar below containing water. A bent pipe passes from this vessel to a bucket (large) hanging from a pulley, the supporting ropes then passing round columns in the cellar below the temple doors. On lighting a fire on the altar the air in it is heated and expands, and forces water from the water vessel over by the bent pipe into the bucket. The bucket then falls towards the ground, its attached ropes causing the columns to revolve and open the temple doors. When the altar fire is put out the air contracts, water is sucked back from the bucket, which is pulled up again by a counter weight, and the doors close.

It may be of interest to you to know that this same Heron invented what appears to be the first " fire engine ", a machine mounted on a cart, and provided with two force pumps, hand worked, spraying water in turn. He also invented a device called now "Heron's fountain ", in which air expanded by heating caused a jet of water to be thrown up.

It is remarkable that, as with other scientific activities, there were no further advances in connection with heat worthy of recording in such a brief article as this until the 17th century. Ewing, a modern authority on the subject, says baldly, "From the time of Heron to the 17th century there is no progress to record ". The Romans were not initiators, but copyists, and gave no new ideas to the world. They certainly talked about heat, and speculated as to its nature, but made no advances on the work of the great Greeks, their predecessors. The Romans were excellent talkers, fighters and military engineers, but could otherwise be dropped from scientific history without loss ; the greater part of old world knowledge which was distributed at the beginning of the Renaissance in the 17th century came from the Greeks through the Arabs ; in certain sections of science the Arabs made definite new contributions of great value.

Speculation as to the nature of heat led to many discussions, unsupported by experiment, right down to comparatively recent times. Lucretius, the Roman author of "De rerum Natura", followed the Greeks in his acceptance of heat as a "substance". This view was not finally discarded until some seventy years ago. It was not until the 17th century that rapid advances in experimental work in connection with heat were made. Galileo is credited with the invention of the thermometer, by means of which temperatures could be compared—this was possibly as early as 1592—but at any rate he was employing it in 1603, so we may date it at the very beginning of the 17th century. His "thermometer" introduced all sorts of errors which were not understood or appreciated at the time. It consisted of a bulb about the size of a hen's egg, from which issued a long stem. This contained air, and was stood *bulb up* with the open end of the stem below the surface of some water in an open vessel; to get the water to rise in the stem to begin with the bulb was heated so that some of its contained air was driven down the stem and escaped; on cooling again, water rose in the stem. Subsequent changes in temperature were compared by the rise and fall of this water column in the vertical tube. (Think of the errors here introduced!)

The first to use a thermometer with liquid in the bulb, which rose and fell in the stem with changes in temperature, was the Frenchman Jean Rey. This was in 1632. Even then the stem was left open, so that there was continual loss of water by evaporation. It was not until some twenty-five years later that the thermometer was sealed, probably at the suggestion of Grand Duke Ferdinand II of Tuscany, the tube then being filled with spirits of wine, and a graduated scale being attached to the stem.

The earliest consistent set of daily temperature records was made in Florence in 1665.

Fixing the scale of temperatures caused considerable difficulty; we did not get our fahrenheit scale until 1724, nor our centigrade scale till 1750. The Florentines decided to take as an upper point "the temperature in the bodies of cows and deer"—rather a vague temperature. The lower point was to be the temperature of snow or ice in the severest frost. In this arbitrary scale they found the temperature of melting ice to be a constant at $13\frac{1}{2}°$.

Dalencé, in 1688, used the temperature of the air during frost and the melting point of butter—again very vague temperatures. In 1665 Huygens had recommended our present standard temperatures, that of melting ice and of boiling water, but they were not adopted. It is very difficult for you, looking backwards, to appreciate any difficulty with regard to thermometry ; that is merely because you have fixed scales of temperature, to which you and everyone else are accustomed, and by which you can record small temperature changes accurately.

Gabriel Daniel Fahrenheit, who lived from 1686 to 1736, gave us the popular fahrenheit scale ; he it was, also, who found that the boiling point of water varied with the pressure on it—a very important fact. It was a lack of knowledge of that which prevented the adoption of the air thermometer of Guillaume Amontons about twenty years previously. It is very interesting to watch the rapid development of thermometry as additional information became available—experiment always should lead to fresh experiment, which accounts for the rapid increase in our knowledge since physics was put on an experimental basis—and may give you some indication of what our knowledge is likely to be in another short period of 200 years.

The centigrade calibration was due to Anders Celsius, in 1742, except that he called the melting point of pure ice 100° and the boiling point of water at standard pressure 0°. This was inverted eight years later, possibly by his colleague Strömer, possibly by one Christin.

Making new scales became a popular pastime ; by 1740 there were at least thirteen different systems, and by 1779 at least nineteen. Now all except three have been forgotten, and of those only two, the fahrenheit and centigrade systems, are in use in Australia. Scientists employ the centigrade scale.

The subsequent development of thermometry is a very interesting study. Many text books on the subject of "pyrometry", as it is called, are published, and temperatures can be recorded from low ones, such as those of the boiling points of hydrogen or helium, to the surface temperatures of distant stars.

Returning to the subject of heat engines, apart from toys based on the engine and fountain of Hero, the next distinct advance was the advocacy in 1606 by Giovanni Della Porta of a device for pumping water. It was in effect a "Heron's fountain", except that steam instead of air entering a vessel forced the contained water up to higher levels. He also suggests that when the steam is cut off from the vessel the vacuum formed might be used to cause the water to rise from a lower level.

In 1629 Giovanni Branca designed another type of steam turbine—an impulse turbine. You will remember that the reaction type had been the principle of Heron's engine over a hundred years B.C. In Branca's engine a jet of steam impinged on to the vanes of a little windmill, causing it to rotate and drive other machines. This idea was to be improved and built into our modern steam turbines.

Probably the next big advance was in the development of another type of heat engine, the cannon. The method of preparation of gunpowder is supposed to have been known to Marcus Græcus in the 8th century, and was known to Albertus Magnus in the 13th century A.D. But it was not until the end of the 14th century that firearms were used. Gunpowder engines, to perform useful work, were tried early in the 17th century. The most important of these engines was that due to Huygens in 1680; in this were introduced for the first time the piston and cylinder as we now have them.

Steam engines were not of common civil importance until about the beginning of the 18th century. In 1698 Savery patented his " water-raising engine ". In Savery's engines there were no pistons. Steam was admitted directly into a vessel from a boiler, then the boiler cut off by closing a valve. Water poured over the outside of the vessel caused the steam in it to condense, so that the partial vacuum thus formed caused a valve to be opened in a downpipe into the mine or well, and water rose into the vessel. When this stage was completed, steam was again admitted from the boiler to the vessel, under a pressure of about 100 pds./sq. inch (7 atmospheres). This closed the valve on the downpipe into the well, and opened a valve on an up-pipe, up which the water was then forced from the vessel. In his double-acting engine two vessels worked alternately, thus keeping up a more uniform pumping. Savery employed pressures on his boilers of as much as 140 pds./sq. inch, and had no safety valves. He was quite upset because the heat melted the common solder he used in assembling the boilers and compelled him to use spelter to make all his joints. The efficiency of this engine was less than 1 %—that is, for every 100 tons of fuel burnt at least 99 tons did no mechanical work.

The safety valve was invented by Papin about 1680. Papin had been associated with Huygens in the construction of gunpowder engines, and was the first to attempt a steam engine employing a cylinder and piston. His engine was not a success, however, as he used the one vessel to act as both boiler and cylinder. A little water was placed at the bottom of the cylinder and a fire put under it. The water boiling, the steam forced the piston up. The fire was then removed, the steam cooled and condensed, and the piston fell. This was repeated regularly, and that was the steam engine. It is amusing to contemplate stokers dashing about on a modern liner placing fires under boiler-cylinders and removing them. But the idea was there, and its development has given us our modern reciprocating steam engines.

Newcomen was the first to improve on Savery's piston engine, by separating boiler and cylinder and using a jet of water squirted directly into the cylinder to condense the steam. This engine was introduced for mine pumping in 1711, a boy being employed to operate the valves to admit steam from the boiler and a jet of cold water alternately. Later automatic gear was employed to do that. Slightly improved by Smeaton, this type of engine was employed until 1770, when the new engines of one James Watt superseded it. It is interesting to note that Savery really introduced the use of the term "horse-power".

Applied physics, such as we have just been discussing, is dependent upon advances made in pure physics, so it will be interesting to see how pure physics was developing at this time.

Joseph Black, who lived between 1728 and 1799, and was at one time professor at Glasgow and later—after 1766—at Edinburgh, discovered and discussed what are known as the "latent heats" associated with the melting of ice and the boiling of water. His results were not very accurate, and his theoretical deductions based on the prevalent belief that heat was a substance were wrong, but it was a knowledge of Black's work which led to Watt's improvements in the steam engine.

You will remember that the Greeks taught that heat was a material substance. This view persisted through the centuries, and early in the 18th century we find George Stahl teaching at the University of Halle that a burning body gave off a material called "phlogiston". Their theories as to the nature of this alleged "matter" are interesting, and engaged the attention of such celebrated men as Euler in 1738, and the well known Frenchman Marat, of Revolutionary fame, in 1780. Although the 17th century scientists had doubted the Greek teachings and inclined to the view that heat was probably due to molecular motion (though without the support of experimental evidence), the close of the 18th century saw the materialistic theory of heat practically universally taught and accepted. The famous chemist Lavoisier, who was decapitated during the revolution, had previously given the supposed material the name of caloric.

The materialistic theory was challenged by Count Rumford who, in 1798, carried out his famous cannon boring experiments at Munich. He found that he had at his disposal an unlimited supply of heat from the same cannon and blunt boring instrument, the heat energy produced being employed to heat water, and being dependent on the work done by the boring apparatus. Naturally, Count Rumford's work was attacked by the supporters of the caloric theory, and some possible explanations of his results were put forward. But Humphry Davy performed the following year—1799—some experiments which apparently completely refuted the materialistic theory. Amongst other experiments, he melted ice by friction in the open air, although the surrounding temperature was below freezing point, thus meeting some objections which had been raised by the materialists. (These experiments of Davy have been attacked in a recent issue of *Nature*, but they are of historical interest.)

The efforts of Rumford and Davy met with little support, the quantitative work being insufficient. The next worker of importance to us in this field was James Prescott Joule, born in 1818. He became a brewer, and remained a successful brewer even whilst carrying on his scientific work. He may be looked upon as an amateur physicist, interested mainly in heat and electricity. By his famous churn experiment, in which he preserved the mechanical work done in churning water and compared it with the heat energy produced, he obtained the relationship between the two forms of energy, and derived what is referred to as the "mechanical equivalent of heat". Joule had no official status, so that his ideas and results were not immediately accepted; it was the endorsement of his work by William Thomson, later Lord Kelvin, which led to this recognition.

The theoretical basis of the design and operation of our modern heat engines was also established about this time. The honour must be awarded to Nicolas Léonard Sadi Carnot, commonly called Sadi Carnot for short, a French military engineer and mathematical physicist. Although he was a believer in the then accepted "caloric" theory of heat, he worked out the beginnings of our modern thermodynamics, calculating amongst other things the possible efficiency of heat engines. His work on the subject was published in 1824 but, though its importance was recognised by a few, its significance was not appreciated until 1849, twenty-five years later (and seventeen years after his death), when we again see William Thomson, Lord Kelvin to be, ensuring general recognition of the importance of the work. Thomson modified Carnot's work, bringing it into accord with the new dynamic theory of heat, the truth of which Carnot had recognised in his later but unpublished papers.

A very fundamental law of heat—simply stated, that "heat cannot, of itself, pass from a colder to a hotter body", was formulated by Rudolph Clausius of Berlin in 1850. This is known to students as the second law of heat, Joule's statement of the simple equivalence of heat and mechanical energy being the first law.

Applied physics, as concerned with heat engines, made use of the information supplied, and although the theoretical results I have mentioned just now were not generally available or accepted until our father's times, you have only to call upon your own knowledge to recall the wonderful advances in the development of heat engines over the last sixty years. The work of that period has been so immense that it would be impracticable to give an abstract in this article of the research workers and their results. My effort must be to paint the advance in broad sweeps, but I would ask you to observe the significance of the mutual assistance of pure scientists and engineers and to note how rapidly today new facts are being observed and applied.

THE PRODUCTION OF ELECTROLYTIC ZINC AT RISDON.

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As the details of this process are rather too intricate for the average student, a summary of the process has been given first, and fuller treatment of the various stages is then added for those interested.

Zinc blende (ZnS) along with galena, pyrites and many other compounds is mined at Broken Hill. The zinc blende is separated from most of the galena. Then the