Федеральное агентство по образованию
Ульяновский государственный технический университет

Техническое чтение для энергетиков

Методическое пособие по английскому языку
для студентов 1, 2 курсов энергетических специальностей
дневной и заочной форм обучения.

Составитель Г.П. Бухарова

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Рецензент доцент цикла «Лингвистика» УлГТУ, кандидат филологических наук, доцент Н. С. Шарафутдинова

Одобрено секцией методических пособий научно-методического совета университета

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Работа выполнена на кафедре «Иностранные языки».

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THE NATURE OF THE ATOM

All the prime movers, natural and man-made, which, humanity has harnessed to ease its burden of labour and raise its standard of living are, in fact, attempts at utilizing the energy of the sun: it sustains organic life on earth with its light and heat, it makes the water circulate between the heavens and the sea, it creates the wind, and it has filled for us a vast storehouse of coal and oil, the mineral deposits from old ages of vegetation. What our inventors did when they built power-producing engines was to change one form of energy–such as the heat of burning coal – into another, the mechanical energy of rotating wheels or the light of an electric lamp. They could not create energy from nothing; they could only release it by some chemical process. This means that although the molecules, or combinations of atoms, may break up and form new combinations, the atoms themselves remain intact and unchanged.

There is one source of energy, however, which owes nothing to the heat and light of the sun; nor can it be harnessed by a chemical process. It is the energy of the atomic nucleus.

The term 'atom', coined by the Greek philosopher Democritus about 2,500 years ago, is rather misleading. It means 'the indivisible', and it is a relic from the times when people believed that all matter consisted of very small particles which were Unchangeable and indivisible, and that each element had its own special kind of particles. Only the medieval alchemists hoped that they could, by some magic, change the particles of one element into those of another – lead, for instance, into gold.

Today we know that atoms are neither unchangeable nor indivisable. The story of research into the nature of the atom has been told many times. It may be sufficient to recall that Marie and Pierre Curie, by their discovery of radium, in 1898, made the whole theory of the indivisible atom crumble, because here was an element which disintegrated and sent out rays, consisting of particles much smaller than the atom.

Another discovery, made three years earlier, seemed to point in the same direction: that of the X-rays by Professor Wilhelm Konrad Rontgen at the University of Bavaria. Using a cathode-ray tube, he found that the radiation emanating from it was able to penetrate thin matter like wood and human flesh, but was stopped by thicker objects such as pieces of metal and bones. It was only later that the nature of these mysterious rays was discovered: particles of negative electricity, called electrons, turn into electro-magnetic waves, of the same kind as light but of shorter wave-length and therefore invisible, when they strike a material object such as a metal shield in the cathode-ray tube.

These and other phenomena and discoveries around the turn of the century were deeply disturbing for the physicists, and they saw that the whole traditional concept of the structure of matter had to be completely revised More than that: the borderline between matter and energy seemed to disappear. When, as early as 1905, Albert Einstein published his Special Theory of Relativity, in which he declared that matter could be converted into energy– very little matter into very great energy – there was a storm of protest in the scientific world. But little by little the evidence that he was right accumulated, and within a few years an entirely new picture of the atom emerged from the studies and laboratories of scientists in many countries. From that evidence Lord Rutherford, the New Zealand-born scientist, and his young Danish assistant, Niels Bohr, developed by 1911 their revolutionary theory of what the atom was really like.

That picture of the atom has since been elaborated and filled in with more details. It is not yet complete; but its essential features are known to be correct – otherwise there would be no atomic bombs, which few people would regret, or nuclear power stations.

Broadly speaking, the atom is a miniature solar system, with a 'sun', the nucleus, and a number of 'planets', the electrons, revolving around it. All the matter of the atom is concentrated in the nucleus: there are protons, particles with a positive electric charge, neutrons, particles without a charge, and some other particles whose role and nature is still being investigated. The electrons, which have next to no mass and weight, are negatively charged; in fact, they are the carriers of electricity in all our electric wires and appliances.

Normally there are as many positive protons in the nucleus as there are electrons revolving around it, so that their charges cancel each other out and the atom as a whole is electrically neutral. But if for some reason an atom loses a proton or an electron or two, its electrical balance is disturbed, it becomes negatively or positively charged and is called an ion.

The atoms of all the elements contain the same kind of particles; what distinguishes them from each other is merely the number of particles – of protons in the nucleus and of electrons revolving around it. Hydrogen, for instance, being the lightest and simplest element, has only one of each; uranium, the heaviest element occurring in Nature, has 92. So all you have to do to change one element into another is either to knock some protons and a corresponding number of electrons off each atom, or add them; in fact, this process is going on in Nature all the time. Theoretically, we could change lead into gold, as the alchemists dreamed of doing, by removing three protons and electrons from a few billion lead atoms, which have 82 of each, then we would get gold atoms with 79 protons and electron each. However, the knocking-off process would be much more expensive than the gold we would get.

The neutrons, which are present in the atoms of many elements, are of particular importance in the utilization of atomic energy. Most elements are mixtures of ordinary atoms and so-called isotopes: the isotope atoms have more, or fewer, neutrons than the ordinary atoms. An isotope differs from the ordinary form of the element only in weight, but chemically it behaves in exactly the same way. Water, for instance, is a mixture of ordinary molecules of hydrogen and oxygen atoms and of 'heavy' ones. The heavy hydrogen atom has an extra neutron in its nucleus. Uranium, on the other hand, has an jsotope whose nucleus contains fewer neutrons than the ordinary element. This isotope – atomic weight: 235; atomic weight of ordinary uranium: 238 – has a very special significance in nuclear physics because it is, like many other heavy-element isotopes, 'unstable'.

What does this mean? Nothing else but the phenomenon which the Curies discovered in radium. An unstable nucleus is one that is likely to break up into the nucleus of another element. Professor Otto Hahn found in Berlin in 1938 that when uranium atoms are bombarded with neutrons they split up in a process which he called 'fission' (a term used in biology for the way in which some cells divide to form new ones). The 92 protons of the uranium nucleus split up into barium, which has 56, and krypton, a gas with 26 protons. Frederic Joliot-Curie, the son-in-law of Marie Curie, proved some months later that in this fission process some neutrons from the uranium nucleus were liberated; they flew off, and some struck other nuclei, which in turn broke up, liberating still more neutrons. Enrico Fermi, an Italian who had gone to America to escape life under fascism, developed the theory of what would happen if a sufficiently large piece of unstable uranium broke up in this way – there would be a 'chain reaction': the free neutrons would be bombarding the nuclei with such intensity that in no time at all the whole lump of uranium would disintegrate.

But it would nut just turn quietly into barium and krypton as in Berlin laboratory experiment. There were now two smaller nuclei, no longer held together as before but pushed apart by electric repulsion, and flying off at great speed, with neutrons shooting about in all directions. And such sudden display of energy–for movement is energy – would, according to Einstein's famous Mass-Energy equation, correspond to some loss of mass. If the two parts of a nucleus which has undergone fission could be put together again, their combined mass would be smaller than that of the original nucleus. What has become of the missing bits? They have turned into pure energy – into movement, into heat.

This was the theory that led, within the short space of four years, to the first atom bombs. On Monday, 6 August 1945, while cheerful crowds in England enjoyed their first holiday after the end of the war in Europe, one such bomb was dropped on the town of Hiroshima in Japan. It killed or injured nearly 200,000 people. Three days later another bomb was dropped on Nagasaki, with 65,000 victims. The centres of both cities were completely destroyed.

PEACEFUL ATOM

When the world had recovered from the shock of this unimaginable horror, people everywhere asked the scientists how soon they could apply the immense power of the fissioned nucleus to peaceful purposes. But this took much longer. It was considerably easier to use the nuclear chain reaction for distruction than for the production of usable energy for homes and factories–to control it and release it in small doses. Many problems had to be solved; the main one was that of 'braking' the released neutrons efficiently so that the chain reaction would not get out of hand.

The first atomic 'pile' or 'reactor', as the apparatus for the utilization of atomic energy is now called, had been Set up by Enrico Fermi on the football ground of the University of Chicago in 1942. It was a somewhat crude assembly, whose main purpose was to get experimental proof for the theory of chain reaction. Fermi scattered rods of uranium through a stack of graphite blocks, which acted as a brake for the neutrons – a 'moderator', to use the technical term. Fermi used natural uranium, which is a mixture of the stable U-238 and the unstable U-235 in a proportion of 140 : 1. Thus there was only slight radioactivity, i. e. breaking-up of nuclei. In order to control it, Fermi inserted some cadmium rods into the pile; this metal absorbs neutrons very readily, and by pushing the rods completely into the pile he could stop the chain reaction altogether.

Fermi's assembly is still the basic blueprint of today's nuclear reactors. Their main parts are the fuel, the moderator, the control rods, and the cooling system. But the scientists and technicians have since developed a great many different types of reactors – some already in everyday use, others running experimentally in atomic research establishments or being built for special jobs and purposes of all kinds, from producing nuclear explosives for weapons to 'cooking' stable elements' so that they become unstable isotopes for use in medicine, industry, agriculture, and research.

Why do we speak of the atomic age as a new chapter in the history of civilization, and why have the technologists made such great efforts to utilize the energy of the split nucleus? For a long time the shadow of a future without sufficient fuel loomed over mankind. Coal has been mined at a steadily increasing pace which set in with the industrial Revolution, and some experts predicted that in Britain, for instance, an acute shortage of cheaply mined coal would set in after 1980. Oil is still to be found in plenty, but consumption has been increasing in leaps and bounds all over the world.

Atomic energy is produced in a different way. It is not generated by the chemical process of combustion. It is released when nuclei undergo fission, and although here» too, matter is used up, the amounts are small compared with the energy produced. A few pounds of uranium 235 can be made to supply a medium-sized town with all the electricity it needs during a whole year. True, our reserves of uranium are limited. But there is one reactor type, which in fact produces more nuclear fuel than it uses! This type has a 'blanket' of thorium, one of the most common elements on earth, which is turned into the artificial radio-active element plutonium when bombarded by neutrons. And there is good reason to hope that before long[1] we shall be able to produce energy from ordinary sea-water by another nuclear reaction called 'fusion'.

So there is little doubt that mankind's energy problems will be solved in the near future, if they have not been solved already in principle. All we have to do is build nuclear reactors and supply them with atomic fuel. But how do we turn it into usable energy?

The 'classical' solution of this question, although it may soon be regarded as an old-fashioned one, is to conduct the heat generated by the fission process out of the reactor, make it boil water, and let the resulting steam drive turbines which, in their turn, drive electric generators. It is a roundabout way, but it works well, although it is still rather expensive.

Britain's first two nuclear power stations were Calder Hall (opened in 1956) and Chapelcross (1959), both of the same type. The reactor 'vessel' a giant steel cylinder, contains a pile of pure graphite, the material from which pencil leads are made. It has many hundreds of vertical or vertical and horizontal channels; in some of them the fuel – rods of uranium metal in magnesium alloy sheaths – are stacked, in the rest there are the control rods made of boron or cadmium; these can be pushed in and pulled out. A very thick concrete or steel wall around the reactor vessel–-the 'biological shield' – prevents the escape of radio-activity.

As soon as the control rods are pulled out the chain reaction begins; uranium nuclei split up under neutron bombardment, and release more neutrons. These neutrons bounce off the graphite atoms so that they shoot to and fro through the reactor until they hit and split more uranium nuclei: the graphite acts as the moderator in this process, helping to keep the chain reaction going and preventing the 'capture' of fast neutrons by the nuclei through slowing them down. The uranium rods get hot (up to 400° C, in Calder Halland Chapelcross), and this heat is removed by the 'coolant', carbon dioxide gas under pressure. It circulates through the reactor vessel in tubes entering at the bottom at 140° C and leaving it at the top at about 340° C The coolant gas, after leaving the 'core' of the reactor, is conducted to the heat exchangers. They are basically ordinary boilers in which water is turned into steam. The water is contained in steel pipes around which the hot coolant gas is blown. The resulting steam is directed into the turbines which rotate the electric generators. Calder Hall and Chapelcross have eight of them each, generating 180,000 and 140,000 kW respectively of electricity, which is fed into the national grid.

If the chain reaction gets too fast and the reactor becomes too hot, the control rods are lowered into the core automatically, thus slowing down the process; if pushed in completely they will stop it altogether.

Uranium as the fuel, graphite as the moderator, and carbon dioxide gas as the coolant are only one possible combination.

Some nuclear engineers believe that organic substances can be used as moderators and coolant fluids, others that the fuel should be given the form of a ceramic. A good deal of research work is done with various types of homogeneous reactors, in which fuel, moderator, and coolant circulate as a single, fluid mixture.

Nuclear power is still in roughly the same early phase as steam power was at the beginning of the nineteenth century, and it may not reach maturity until the end of our own century. By that time, however, we shall not only have fission but also fusion as a basic energy-producing nuclear process.

The theory of nuclear fusion was discovered in the early 1930's – years before that of fission – by John Cockeroft at the Cavendish Laboratory, Cambridge, where he worked under Lord Rutherford. Here they built a simple machine, which looked more like a couple of stove-pipes than an atom-smashing tool, for shooting electrically speed-up protons at the nuclei of light elements, such as lithium. The result was that the lithium nuclei turned into nuclei of helium. This was strange; for helium is heavier than lithium. Somehow the helium atoms must have been formed not only by splitting but by subsequent accumulation of protons and neutrons. It was only later that it dawned on the physicists that some such process is responsible for the way in which the stars, including our own sun, produce their tremendous energy.

Today we know that in the sun light elements – mainly hydrogen –are turned into heavier ones, such as helium. This 'thermo-nuclear' process of fusion, as it is called, takes place at fantastically high temperatures (in the centre of the sun the temperature is believed to be about 15 million degrees Centrigrade). The heat fuses the nuclei, which would normally repel each other because they have the same (positive) electrical charge; heat means violent movement of particles, in other words: energy. Thus the hydrogen nuclei bump into each other and combine to form helium nuclei, with a simultaneous release of energy. As in nuclear fission, some mass is converted into energy in the fusion process, but the sun can keep up its rate of loss of mass – five million tons per second – for some thousands of million years.

This process is only possible where light elements are concerned; hydrogen, the lightest of them, has the smallest electrical charge, and therefore the repellent force of its nuclei can be more easily overcome than that of heavier elements. If there was any chance at all of producing nuclear energy from fusion – this was a point about which scientists agreed – it could only be done by using hydrogen: in short, by emulating on earth the process that makes the sun shine.

Again, as in the case of atomic fission, this was first achieved in the form of a weapon, the hydrogen bomb. Even the testing of this weapon has proved to be highly dangerous because it contaminates the atmosphere all over the world with radio-active 'fall-out' isotopes which can produce cancer of the bone and blood. No one doubts that a nuclear war fought with fission and fusion bombs would mean the suicide of mankind.

As these lines are being written many scientists in at least half a dozen countries are busy trying to find a system to tame the energy of the H-bomb for peaceful use, but no decisive 'break-through' has been achieved. It may, however, come at any moment. In August 1957 British physicists working with their thermo-nuclear device called '2eta' believed they had succeeded, but this turned out to be a mistake. Still, the scientists' efforts towards that goal are all based on the same basic principle, and some time somewhere another Zeta will achieve the 'break-through'.

In these experiments the heavy hydrogen isotope deuterium – which has an extra neutron in its nucleus – plays the decisive part. At very high temperatures the protons are detached from the electrons revolving around them, and the neutrons fly off at great speed, thus providing extra energy, i. e. heat, as the protons melt together to form new nuclei. There are many difficult problems to overcome before the thermo-nuclear power station based on this process can become a reality, but that of fuel supply is the least of them: the oceans of the earth are practically inexhaustible source of deuterium, and its extraction from sea water is neither complicated nor expensive. One gallon of sea water may be sufficient to yield as much energy as 100 gallons of petrol, and a bucketful containing one-fifth of a gram of deuterium could keep a five-room house warm for a whole year.

The real trouble starts when we attempt to produce the very high temperatures required to achieve thermo-nuclear fusion. Up to 1950, the highest temperature ever produced in a laboratory was 30,000° Centigrade. All the Zeta-type assemblies, therefore, are machines designed to reach temperatures of many millions of degrees for heating deuterium gas. This is done electrically. When an electric current is passed through a gas it sets up an electric discharge in it, with a corresponding rise in temperature. A hollow vessel – either ring-shaped or tube-shaped, and usually made of aluminium – is partly encircled by a huge electromagnet which produces the field that heats up the deuterium inside. But if the hot gas touched the walls of the vessel they would melt, and the gas would cool down; therefore, it must be kept in the centre. This is done by another intense magnetic field around the gas, usually by winding an electrically charged cable around the vessel. In this way the gas, which tries to resist that 'pinch effect', is prevented from behaving about like an angry snake as soon as the current is switched on and the temperature rises.

Zeta, the British assembly which was originally built at the atomic research establishment, had a ring-shaped form; the 'pyrotfon[1], set up at the University of California, was designed as a linear tube with a special 'mirror' effect: the magnetic field was made much stronger at either end so that the 'plasma', as the gas in the machine is usually called, assumed the shape of a sausage – thick in the middle and pinched at the ends. This arrangement had the effect of a magnetic mirror; the particles racing around in the plasma were reflected back from both ends into the centre, which increased the temperature and also the probability of the particles bumping into each other to achieve fusion. Another American fusion research instrument did away with the magnetic coils, and used a layer of accelerated electrons instead for the production of the necessary magnetic field.

When one of the scientists' teams working with these machines achieves genuine fusion – a temperature of up to 500 million degrees Centigrade may be needed to start a thermonuclear process which can maintain itself–the question of how a thermo-nuclear power station could work will become topical. As in a conventional power station, coal-fired or atomic, the heat could be used to produce steam for the turbo-generators. But by that time there may be a better and more direct way of turning heat or radio-activity into electricity.

There are several basic systems of doing this. One, called the 'thermionic converter', uses the principle of the cathode-ray tube in which electrons, particles of negative electricity, are given off by a hot strip of metal, the cathode, in a vacuum. The heat necessary to produce this effect could be that generated in a nuclear reactor; the greater the temperature difference between the cathode, or 'emitter', and the anode, or 'collector', the greater will be the yield of electrons and therefore of electric current. There is, at least theoretically, no reason why a nuclear power station should not be operating on this principle once the technological problems have been solved.

Atomic as well as conventional power stations may be made much more efficient by the gas-blast system of generating electricity. It is based on the fact that a blast of very hot gas (at least 2,000° Centigrade), which could be produced by a fission or fusion reactor, becomes an electrical conductor and generates current when moving through the poles of a powerful magnet. American and British research laboratories are working on this scheme, but the principal problem is that of finding materials which can withstand such temperatures for any length of time.

Another system – which might be better suited for smaller, mobile electricity producing units – is based on a discovery recorded already by the Curies around 1900, but neglected by scientists for nearly half a century. That was the observation that radio-activity could produce electricity directly in certain materials. When, after the Second World War, cheap radio-active sources–isotopes–became available the idea was taken up at last. The first, somewhat crude 'atomic battery', as it was called, was produced in 1954 by a research team in the laboratories of the Radio Corporation of America: a little box containing a thin wafer of the isotope, strontium 90 – one of the dangerous elements in radio-active 'fall-out' after H-bomb tests; it bombarded with its particles a semi-conductor crystal, an adaptation of the transistor. The current generated in the crystal by the radio-active emanation of the strontium was strong enough to produce a buzzing noise in an earphone.

Isotopes for direct generation of electricity will be available in growing quantities as the utilization of atomic energy spreads to more and more countries. One of the major problems connected with nuclear power stations is the safe disposal of radio-active waste; burying it, or dumping it into the sea, is not everywhere the best means of getting rid of it. But when devices such as atomic batteries are mass produced they will require great quantities of radio-active 'waste' products; they must, of course, be made absolutely safe for everyday use.

How can we tell if we are the target of radio-active emanation? It is invisible and inaudible, and we cannot feel it – unless and until we have received too much of it and become ill. But there is a vital tool in our nuclear age, the Geiger counter in its manifold forms, which measures radio-activity accurately. Invented by Hans Geiger, a German physicist and one of Lord Rutherford's close collaborators, in the 1920's, it is an ingenious instrument which can make any type of radiation, whether in the form of particles or of electro-magnetic waves, visible and audible.

The Geiger counter consists of a metal cylinder filled with gas at low pressure; two electrodes – one being the cylinder itself, the other a fine wire stretched along its centre – are maintained at a large potential difference, usually about 1,000– 1,500 volts, but no spark is allowed to pass between them. Only when some subatomic particle or unit of electro-magnetic radiation pierces the thin metal of the cylinder and produces ionization (i. e. when the gas atoms become electrically charged), there is a sudden discharge between the electrodes, and the potential drops for the fraction of a second. This can be made either visible on a dial, or audible in a pair of headphones. Frequently, simple counting devices such as telephone counters are attached to the tube to register the number of incoming particles.

Geiger counters are being made and adapted for all kinds of purposes–light ones for uranium prospecting; built-in types for atomic power stations and research establishments; counters with warning signals for factory workers who have to handle radio-active matter and whose hands and clothes have to be checked; counters which can test human breath for traces of radon gas, and so on.

Finally, a new source of energy could be created by 'depositing' the heat of a nuclear explosion deep underground and using it – just as volcanic heat is used in some parts of the world – for the production of power. It has been estimated that an atomic blast 3,000 feet underground in a suitable geological formation would produce about 8,000 million kilowatt hours of electrical energy at a cost of 0.04 d. (less than-y cent) per kilowatt. In short, the peaceful uses of atomic energy are vast and tempting – but we must stop squandering it on weapons of mass annihilation.

SOLAR ENERGY

We know that all the energy mankind has ever used comes from the sun, with the exception of nuclear energy. If we took all the world's reserves of coal, oil, and natural gas and burnt them up at the same rate at which we receive the sun's energy, our whole supply would last less than three days. Yet we are only now beginning to use that vast and almost inexhaustible source of energy in the sky directly.

The most primitive device for catching and trapping the heat of the sun is the gardener's greenhouse. Its modern off-spring is the solar water-heater, usually a coil of pipes placed in a shallow box on the roof of a house, embedded in black concrete (black accepts the sun rays more easily, white reflects them) and covered with a glass pane. The water circulating in the pipes is heated by the sun and then pumped into a hot-water tank from which the household takes its supply. In Florida alone, more than 50,000 homes get their hot water in this way, and in Israel it has become general practice to install solar water-heaters in new rural houses.

A more complicated but also more efficient device is the heat pump. It is, in fact, a refrigerator in reverse. It picks up as much heat as it can get either from the atmosphere, the soil, or from water (a river jar a lake); this amount of heat, which is of course rather small in winter, is made to act on a liquid with a very low boiling-point so that it changes into a gas. The gas is then compressed by means of a pump and goes into a condenser coil, where it changes back to a liquid, thus setting its heat free; this can be made to heat the house or to provide hot water. Many heat pumps can be switched to reverse action so that they cool the air in summer.

Various types of 'solar houses' have been designed by engineers and architects, especially in America, where many thousands of them have been built. In these houses, some medium is used to store the heat of the sun and release it gradually as required. Water is a good medium for the purpose, but Glauber's salt (hydrated sodium sulphate) is even more efficient. It melts at a temperature of 90° F., taking in a large amount of heat which it releases again when it turns back into crystals. Twenty tons of the salt in the cellar of the solar house have been found to be sufficient to keep the rooms comfortably warm in winter–with heat collected in the summer!

Another interesting medium is gravel, incorporated in the walls of the house, which it keeps warm on sunless days; by means of a small ventilator, hot air from a heat collector on the roof is circulated through the gravel, which releases its accumulated heat at an even rate.

These efforts at utilizing the heat of the sun show that the engineers are well aware of the great possibilities of solar heating but also of its limitations. Many countries, especially in what we call the moderate zones (to say nothing of the cold regions), do not enjoy enough sunshine to make a solar house worth building, while the tropical zones have no use for extra heat. There, however, cooking by solar energy is becoming more and more important in everyday life.

India has a very limited supply of fuel – its main source for the home is dried cow dung, which of course would be much better employed in fertilizing the soil. But India has an abundance of sunshine. As early as the 1880's, an Englishman working in India suggested the introduction of a cheap solar cooker, but until fairly recently no really efficient device suitable for mass production had been invented. The Indian National Physical Laboratory and one of the United Nations agencies eventually developed solar cookers, which are being used in creasingly in Indian homes. One type uses a reflecting mirror and a pressure cooker, another has four flat mirrors and an insulated heat-collecting box filled with Glauber's salt crystals, which continue to release heat when the sun has already set.

In the Sudan and East Africa a simple type of solar cooker has become fairly popular. It consists of a concave aluminium reflector 4,25 feet across, mounted on an upright iron rod; the concentrated rays of the sun fall on the pot or pan placed on a wire-mesh holder which is attached to the reflector.

Another very important device is the solar 'still' for the distillation of fresh water from salt water, usually working on the principle of a salt-water container covered by a sloping glass roof; as the heat of the sun evaporates the water, the vapour condenses in droplets on the glass roof from where they trickle down into a fresh-water collector. The equally valuable salt is left behind in the saltwater container.

Solar furnaces are still very much in the experimental stage. French scientists are operating them in their research station in the Pyrenees; they are very large – one has a flat reflecting mirror made up of 516 panes and covering an area of 43 feet square and a 31-foot by 33-foot parabolic mirror at a distance of 80 feet. The heat produced by this arrangement is sufficient to melt 130 lb, of iron per hour. The Russians have built an enormous 'helio-boiler', consisting of an 80-foot tower surrounded by twenty-three concentric railway tracks; bogeys move around on these tracks, each carrying a 10-foot by 16-foot reflector to concentrate the sun's rays on to a boiler in the tower. It is claimed that this machine produces enough superheated steam for a turbogenerator with 1,000 kW output.

The most efficient way of generating electricity from sunlight, however, seems to be the 'solar battery'. The first of this type was demonstrated in 1954 by a team of scientists from the American Bell Laboratories. It operated with semi-conductor crystals similar to those used in transistors either of germanium or of silicon. When sunlight strikes such a crystal, an electric current is generated. A Bell battery of 400 silicon cells was able to produce a 12-volt current. Since its first demonstration, the solar battery has been extensively developed and has taken part in one of Man's greatest adventures – the sending of satellites and rocket vehicles into space. Solar batteries, as well as the already mentioned atomic batteries, are very suitable for powering the transmitters in space vehicles because of their long life.

Eventually, solar batteries may be developed to provide all the low-voltage current needed in a house. Their theoretical top efficiency is 22 per cent, corresponding to the generation of about 200 watts per square yard of the silicon surface.

French scientists have designed a solar lamp. It is about as big as a small suitcase; at the top it has a collector panel consisting of a few dozen photo-sensitive silicon cells, and the solar energy which they collect is stored in a small accumulator. The underside of the 'suitcase' consists of a fluorescent tube. During day-time the device is put out in the sun, and in the evening it is taken indoors and the lamp switched on. Depending on the time the collector has been exposed to the sun the lamp will then shine for a few hours.

Instead of semiconductors the solar battery can also use thermocouples. Here the problem is that of keeping one end of the thermocouple wires cool while the other is heated by the sun – otherwise there will be no current.

In the 1950' s, the Solar Energy Committee of the British National Physical Laboratory made a suggestion which could help to provide tropical regions with perpetual energy: the planting of quick-growing forest wood such as eucalyptus, and its continuous combustion in medium-size power stations. A few square miles of eucalyptus forest would yield enough wood to fire the boilers of the power station for ever because the wood would grow as fast as it is used up.

Electricity from eucalyptus may not be the most efficient system of turning the energy of the sun into power, but it shows the ingenuity of our scientists in finding new ways and means to provide mankind with more and more energy; and that means: to raise its standard of living. In the old days, the stage of civilization reached by a nation used to be measured in pounds of soap per head a year; today it is the amount of horsepower or kilowatt-hours available to everybody which indicates the degree of civilization.

Now we have the technical means of generating enough energy to raise the standard of living to a decent level all over the world, and it is our noblest task for the rest of this century to do it.

SOLAR LIGHT BY NIGHT

Most people living in towns consider it a usual thing that streets are lit at night. But street lights need a power supply (источник энергии) therefore distant areas with no source of electricity remain in darkness until the sun comes up again.

With new appliances now offered by several British firms, many distant places could be lit with solar-powered street lights. It may seem strange that the lamps can use the power of the sun which shines by day when the lamps are needed at night, but they work by using energy accumulated during the day from a solar panel. The solar panel produces electricity which charges (заряжать) a battery. When the sun goes down, the battery power is then used for lighting. Each lamp has its own panel so the system can be used for one individual light or a number of them.

In the south of Saudi Arabia a motorway tunnel miles from any power supply is lit day and night by solar-powered devices. The solar panels provide power during the day and charge batteries which accumulate enough power to light the tunnel at night. The generation of electricity by batteries is still expensive but the advantage of sun-powered lamps is that they can bring light to areas distant from any other power supply.

There is one more advantage of solar power: not only it is unlimited, but also its use does not pollute the environment. That is why it is very important to develop devices which make it possible to transform solar power into mechanical or electric forms of power.

ENERGY

In the language of science energy is the ability to do work. There are various forms of energy, such as heat, mechanical, electrical, chemical, atomic and so on. One might also mention the two kinds of mechanical energy–potential and kinetic, potential energy being the energy of position while kinetic energy is the energy of motion.

It is well known that one form of energy can be changed into another. A waterfall may serve as an example. Water falling from its raised position, energy changes from potential to kinetic energy. The energy of falling water is generally used to turn the turbines of hydroelectric stations. The turbines in their turn drive the electric generators, the latter producing electric energy. Thus, the mechanical energy of falling water is turned into electric energy. The electric energy, in its turn, may be transformed into any other necessary form.

When an object loses its potential energy, that energy is turned into kinetic energy. Thus, in the above-mentioned example when water is falling from its raised position, it certainly loses its potential energy, that energy changing into kinetic energy.

We have already seen that energy of some kind must be employed to generate the electric current. Generally speaking, the "sources of energy usually employed to produce current are either chemical as in the battery, or mechanical, as in the electromagnetic generator. Chemical sources of current having a limited application, the great quantities of electric energy generated today come from various forms of mechanical energy.

The rising standards of modern civilization and growing industrial application of the electric current result in an increasing need of energy. Every year we need more and more energy. We need it to do a lot of useful things that are done by electricity. However, the energy sources of the world are decreasing while the energy needs of the world are increasing. These needs will continue to grow as more motors and melted metals are used in industry and more electric current is employed in everyday life. As a result, it is necessary to find new sources of energy.

The sun is an unlimited source of energy. However, at present, only a little part of solar energy is being used j directly. How can we employ solar energy directly to produce useful energy? This is a question which has interested scientists and inventors for a long time. Lavoisier and other great scientists of the past melted metals with the help of solar furnaces. Today, solar furnaces illustrate just one of the numerous ways to harness the sun. Using semiconductors, scientists, for example, have transformed solar energy into electric energy.

ATOMIC ENERGY

A man trying to see a single atom is like a man trying to see a single drop of water in the sea while he is flying high above it. He will see the sea made up of a great many drops of water but he certainly will not be able to see a single drop. By the way, there are so many atoms in the drop of water that if one could count one atom a second, day and night, it would take one hundred milliard years. But that is certainly impossible.

Man has, however, learned the secret of the atom. He has learned to split atoms in order to get great quantities of energy. At present, coal is one of the most important fuel and our basic source of energy. It is quite possible that some day coal and other fuel may be replaced by atomic energy. Atomic energy replacing the present sources of energy, the latter will find various new applications.

The nuclear reactor is one of the most reliable "furnaces" producing atomic energy. Being used to produce energy, the reactor produces it in the form of heat. In other words, atoms splitting in the reactor, heat is developed. Gas, water, melted metals, and some other liquids circulating through the reactor carry that heat away. The heat may be carried to pipes of the steam generator containing water. The resulting steam drives a turbine, the turbine in its turn driving an electric generator. So we see that a nuclear power-station is like any other power-station but the familiar coal-burning furnace is replaced by a nuclear one, that is the reactor supplies energy to the turbines. By the way, a ton of uranium (nuclear fuel) can give us as much energy as 2.5 to 3 million tons of coal.

The first industrial nuclear power-station in the world was constructed in Obninsk not far from Moscow in 1954. It is of high capacity and has already been working for many years. One may mention here that the station in question was put into operation two years earlier than the British one and three and a half years earlier than the American nuclear power-stations.

A number of nuclear power-stations have been put into operation since 1954. The Beloyarskaya nuclear power-station named after academician Kurchatov may serve as an example of the peaceful use of atomic energy in the USSR.

Soviet scientists and engineers achieved a nuclear superheating of steam directly in the reactor itself before steam is carried into the turbine. It is certainly an important contribution to nuclear engineering achieved for the first time in the world.

We might mention here another important achievement, that is, the first nuclear installation where thermal energy generated in the reactor is transformed directly into electrical energy.

Speaking of the peaceful use of atomic energy it is also necessary to mention our nuclear ice-breakers. "Lenin" is the world's first ice-breaker with a nuclear installation. Its machine installation is of a steam turbine type, the steam being produced by three reactors and six steam generators. This ice-breaker was followed by many others.

The importance of atomic energy will grow still more when fast neutron reactors are used on a large scale. These reactors can produce much more secondary nuclear fuel than the fuel they consume.

MAGNETISM

In studying the electric current, we observe the following relation between magnetism and the electric current: on the one hand magnetism is produced by the current and on the other hand the current is produced from magnetism.

Magnetism is mentioned in the oldest writings of man. Romans, for example, knew that an object looking like a small dark stone had the property of attracting iron. However, nobody knew who discovered magnetism or where and when the discovery was made. Of course, people could not help repeating the stories that they had heard from their fathers who, in their turn, heard them from their own fathers and so on.

One story tells us of a man called Magnus whose iron staff was pulled to a stone and held there. He had great difficulty in pulling his staff away. Magnus carried the stone away with him in order to demonstrate its attracting ability among his friends. This unfamiliar substance was called Magnus after its discoverer, this name having come down to us as "Magnet".

According to another story, a great mountain by the sea possessed so much magnetism that all passing ships were destroyed because all their iron parts fell out. They were pulled out because of the magnetic force of that mountain.

The earliest practical application of magnetism was connected with the use of a simple compass consisting of one small magnet pointing north and south.

A great step forward in the scientific study of magnetism was made by Gilbert, the well-known English physicist (1540-1603). He carried out various important experiments on electricity and magnetism and wrote a book where he put together all that was known about magnetism. He proved that the earth itself was a great magnet.

Reference must be made here to Galileo, the famous Italian astronomer, physicist and mathematician. He took great interest in Gilbert's achievements and also studied the properties of magnetic materials. He experimented with them trying to increase their attracting power. One of his magnets, for example, could lift objects weighing 25 times its own weight.

At present, even a schoolboy is quite familiar with the fact that in magnetic materials, such as iron and steel, the molecules themselves are minute magnets, each of them having a north pole and a south pole. When iron and steel are magnetized, the molecules arrange themselves in a new orderly way instead of the disarrangement in which they neutralize each other.

Dividing a bar magnet into two parts, one finds that each of the two parts is a magnet having both a north pole and a south pole. Thus, we obtain two magnets of a smaller size instead of having a single one of a larger size. Dividing one of these two smaller magnets into two will give us the same result, Thus, we could continue this process, always getting similar results.

On placing an unmagnetized iron bar near a strong magnet, we magnetize it. Rubbing the magnet is not required for that process. In other words, our iron bar has been magnetized by the strong magnet without rubbing it.

EARLY DAYS OF ELECTRICITY

There is electricity everywhere in the world. It is present in the atom, whose particles are held together by its forces; it reaches us from the most distant parts of the universe in the form of electro-magnetic waves. Yet we have no organs that could recognize it as we see light or hear sound. We have to make it visible, tangible, or audible, we have to make it perform work to become aware of its presence. There is only one natural phenomenon which demonstrates it unmistakably to our senses of seeing and hearing – thunder and lightning; but we recognize only the effects – not the force which causes them.

Small wonder, then, that Man lived for ages on this earth without knowing anything about electricity. He tried to explain the phenomenon of the thunderstorm to himself by imagining that some gods or other supernatural creatures were giving vent to their heavenly anger, or were fighting battles in the sky. Thunderstorms frightened our primitive ancestors; they should have been grateful to them instead because lightning gave them their first fires, and thus opened to them the road to civilization. It is a fascinating question how differently life on earth would have developed if we had an organ for electricity.

We cannot blame the ancient Greeks for failing to recognize that the force which causes a thunderstorm is the same which they observed when rubbing a piece of amber: it attracted straw, feathers, and other light materials. Thales of Miletos, the Greek philosopher who lived about 600 B. C, was the first who noticed this. The Greek word for amber is elektron, and therefore Thales called that mysterious force 'electric'. For a long time it was thought to be of the same nature as the magnetic power of the lodestone since the effect of attraction seems similar, and in fact there are many links between electricity and magnetism.

There is just a chance, although a somewhat remote one, that the ancient Jews knew something of the secret of electricity.

Perhaps the Israelites did know something about electricity; this theory is supported by the fact that the Temple at Jerusalem had metal rods on the roof which must have acted as lightning-conductors. In fact, during the thousand years of its existence it was never struck by lightning although thunderstorms abound in Palestine.

There is no other evidence that electricity was put to any use at all in antiquity, except that the Greek women decorated their spinning-wheels with pieces of amber: as the wollen threads rubbed against the amber it first attracted and then repelled them – a pretty little spectacle which relieved the boredom of spinning.

More than two thousand years passed after Thales's discovery without any research work being done in this field. It was Dr. William Gilbert, Queen Elizabeth the First's physician-in-ordinary, who set the ball rolling. He experimented with amber and lodestone and found the essential difference between electric and magnetic attraction. For substances which behaved like amber – such as glass, sulphur, sealing-wax – he coined the term 'electrica', and for the phenomenon as such the word 'electricity'. In his famous work De magnete, published in 1600, he gave an account of his studies. Although some sources credit him with the invention of the first electric machine, this was a later achievement by Otto von Gue-ricke, inventor of the air pump.

Von Guericke's electric machine consisted of a large disc spinning between brushes; this made sparks leap across a gap between two metal balls. It became a favourite toy in polite society but nothing more than that. In 1700, an Englishman by the name of Francis Hawksbee produced the first electric light: he exhausted a glass bulb by means of a vacuum pump and rotated it at high speed while rubbing it with his hand until it emitted a faint glow of light.

A major advance was the invention of the first electrical condenser, now called the Leyden jar, by a Dutch scientist, a water-filled glass bottle coated inside and out with metallic surfaces, separated by the non-conducting glass; a metal rod with a knob at the top reached down into the water. When charged by an electric machine it stored enough electricity to give anyone who touched the knob a powerful shock.

More and more scientists took up electric research. A Russian scientist Professor Richmann from St. Petersburg, was killed when he worked on the same problem.

Benjamin Franklin, born in Boston, was the fifteenth child of a poor soap-boiler from England. He was well over 30 when he took up the study of natural phenomena.

'We had for some time been of opinion, that the electrical fire was not created by friction, but collected, being really an element diffused among, and attracted by other matter, particularly by water and metals,' wrote Franklin in 1747. Here was at last a plausible theory of the nature of electricity, namely, that it was some kind of 'fluid'. It dawned on him that thunderstorms were merely a discharge of electricity between two objects with different electrical potentials, such as the clouds and the earth. He saw that the discharging spark, the lightning, tended to strike high buildings and trees, which gave him the idea of trying to attract the electrical 'fluid' deliberately to the earth in a way that the discharge would do no harm.

In order to work this idea out he undertook his famous kite-and-key experiment[1] in the summer of 1752. It was much more dangerous than he realized. During the approach of a thunderstorm he sent up a silken kite with an iron tip; he rubbed the end of the kite string, which he had soaked in water to make it a good conductor of electricity, with a large iron key until sparks sprang from the string – which proved his theory. Had the lightning struck his kite he, and his small son whom he had taken along, might have lost their lives.

In the next experiment he fixed an iron bar to the outer wall of his house, and through it charged a Leyden jar with atmospheric electricity. Soon after this he was appointed Postmaster General of Britain's American colonies, and had to interrupt his research work. Taking it up again in 1760, he put up the first effective lightning-conductor on the house of a Philadelphia business man.

His theory was that during a thunderstorm a continual radiation of electricity from the earth through the metal of the lightning-conductor would take place, thus equalizing the different potentials of the air and the earth so that the violent discharge of the lightning would be avoided. The modern theory, however, is that the lightning-conductor simply offers to the electric tension a path of low resistance for quiet neutralization. At any rate – even if Franklin's theory was wrong – his invention worked.

Yet its general introduction in America and Europe was delayed by all kinds of superstitions and objections: if God wanted to punish someone by making the lightning-strike his house, how could Man dare to interfere? By 1782, however, all the public buildings in Philadelphia, first capital of the USA, had been equipped with Franklin's lightning-conductors, except the French Embassy. In that year this house was struck by lightning and an official killed. Franklin had won the day.

It was he who introduced the idea of 'positive' and 'negative' electricity, based on the attraction and repulsion of electrified objects. A French physicist, Charles Augustin de Coulomb, studied these forces between charged objects, which are proportional to the charge and the distance between the objects; he invented the torsion balance for measuring the force of electric and magnetic attraction. In his honour, the practical unit of quantity of electricity was named after him.

To scientists and laymen alike, however, this phenomenon of 'action at a distance' caused by electric and magnetic forces was still rather mysterious. What was it really? In 1780, one of the greatest scientific fallacies of all times seemed to provide the answer. Aloisio Galvani, professor of medicine at Bologna, was lecturing to his students at his home while his wife was skinning frogs, the professor's favourite dish, for dinner with his scalpel in the adjoining kitchen. As she listened to the lecture the scalpel fell from her hand on to the frog's thigh, touching the zinc plate at the same time. The dead frog jerked violently as though trying to jump off the plate.

The signora screamed. The professor, very indignant about this interruption of his lecture, strode into the kitchen. His wife told him what had happened, and again let the scalpel drop on the frog. Again it twitched.

No doubt the professor was as much perplexed by this occurrence as his wife. But there were his students, anxious to know what it was all about. Galvani could not admit that he was unable to explain the jerking frog. So, probably on the spur of the moment[1] he explained: 'I have made a great discovery – animal electricity, the primary source of life!'

'An intelligent woman had made an interesting observation, but the not-so-intelligent husband drew the wrong conclusions', was the judgement of a scientific author a few years later. Galvani made numerous and unsystematic experiments with frogs' thighs, most of which failed to prove anything at all; in fact, the professor did not know what to look for except his 'animal electricity'. These experiments became all the rage in Italian society, and everybody talked about 'galvanic electricity' and 'galvanic currents' – terms which are still in use although Professor Galvani certainly did not deserve the honour.

A greater scientist than he, Alessandro Volta of Pavia, solved the mystery and found the right explanation for the jerking frogs. Far from being the 'primary source of life', they played the very modest part of electric conductors while the steel of the scalpel and the zinc of the plate were, in fact, the important things. Volta showed that an electric current begins to flow when two different metals are separated by moisture (the frog had been soaked in salt water), and the frog's muscles had merely demonstrated the presence of the current by contracting under its influence.

Professor Volta went one step further – a most important step, because he invented the first electrical battery, the 'Voltaic pile'. He built it by using discs of different metals separated by layers of felt which he soaked in acid. A 'pile' of these elements produced usable electric current, and for many decades this remained the only practical source of electricity. From 1800, when Volta announced his invention, electrical research became widespread among the world's scientists in innumerable laboratories.

EARLY HISTORY OF ELECTRICITY

Let us now turn our attention to the early facts, that is to say, let us see how it all started.

History shows us that at least 2,500 years ago, or so, the Greeks were already familiar with the strange force (as it seemed to them) which is known today as electricity. Generally speaking, three phenomena made up all of man's knowledge of electrical effects. The first phenomenon under consideration was the familiar lightning flash –a dangerous power, as it seemed to him, which could both kill people and burn or destroy their houses. The second manifestation of electricity he was more or less familiar with was the following: he sometimes found in the earth a strange yellow stone which looked like glass. On being rubbed, that strange yellow stone, that is to say amber, obtained the ability of attracting light objects of a small size. The third phenomenon was connected with the so-called electric fish which possessed the property of giving more or less strong electric shocks which could be obtained by a person coming into contact with the electric fish.

Nobody knew that the above phenomena were due to electricity. People could neither understand their observations nor find any practical applications for them.

As a matter of fact, all of man's knowledge in the field of electricity has been obtained during the last 370 years, or so. Needless to say, it took a long time before scientists learned how to make use of electricity. In effect, most of the electrically operated devices, such as the electric lamp, the refrigerator, the tram, the lift, the radio, and so on, are less than one hundred years old. In spite of their having been employed for such a short period of time, they play a most important part in man's everyday life all over the world. In fact, we cannot do without them at present.

So far, we have not named the scientists who contributed to the scientific research on electricity as centuries passed. However, famous names are connected with its history and among them we find that of Phales, the Greek philosopher. As early as about 600 B. C. (that Is, before our era) he discovered that when amber was rubbed, it attracted and held minute light objects. However, he could not know that amber was charged with electricity owing to the process of rubbing. Then Gilbert, the English physicist, began the first systematic scientific research on electrical phenomena. Rediscovered that various other substances possessed the property similar to that of amber or, in other words, they generated electricity when they were rubbed. He gave the name "electricity" to the phenomenon he was studying. He got this word from the Greek "electrum" meaning "amber".

Many learned men of Europe began to use the new word "electricity" in their conversation as they were engaged in research of their own. Scientists of Russia, France and Italy made their contribution as well as the Englishmen and the Germans.

FROM THE HISTORY OF ELECTRICITY

There are two types of electricity, namely, electricity at rest or in a static condition and electricity in motion, that is, the electric current. Both of them are made up of electric charges, static charges being at rest, while electric current flows and does work. Thus, they differ in their ability to serve mankind as well as in their behaviour. Let us first turn our attention to static electricity. For a long time it was the only electrical phenomenon to be observed by man. As previously mentioned at least 2,500 years ago, or so, the Greeks knew how to get electricity by rubbing substances. However, the electricity to be obtained by rubbing objects cannot be used to light lamps, to boil water, to run electric trains, and so on. It is usually very high in voltage and difficult to control, besides it discharges in no time.

As early as 1753, Franklin made an important contribution to the science of electricity. He was the first to prove that unlike charges are produced due to rubbing dissimilar objects To show that the charges are unlike and opposite, he decided to call the charge on the rubber– negative and that on the glass–positive.

In this connection one might remember the Russian academician V. V. Petrov. He was the first to carry on experiments and observations on the electrification of metals by rubbing them one against another. As a result he was the first scientist in the world who solved that problem.

Who does not know that the first man to get the electric current was Volta after whom the unit of electric pressure, the volt, was named? His discovery developed out of Galvani's experiments with the frog. Galvani observed that the legs of a dead frog jumped as a result of an electric charge. He tried his experiment several times and every time he obtained the same result. He thought that electricity was generated within the leg itself.

Volta began to carry on similar experiments and soon found that the electric source was not within the frog's leg but was the result of the contact of both dissimilar metals used during his observations. However, to carry on such experiments was not an easy thing to do. He spent the next few years trying to invent a source of continuous current. To increase the effect obtained with one pair of metals, Volta increased the number of these pairs. Thus the voltaic pile consisted of a copper layer and a layer of zinc placed one above another with a layer of flannel moistened in salt water between them. A wire was connected to the first disc of copper and to the last disc of zinc.

The year 1800 is a date to be remembered: for the first time in the world's history a continuous current was generated.

Volta's Short Biography. Volta was born in Como, Italy, on February 18, 1745. For some years he was a teacher of physics in his home town. Later on he became professor of natural sciences at the University of Pavia. After his famous discovery he travelled in many countries, among them France, Germany and England. He was invited to Paris to deliver lectures on the newly discovered chemical source of continuous current. In 1&19 he returned to Como where he spent the rest of his life. Volta died at the age of 82.

ELECTRICITY

It is impossible to imagine our civilization without electricity: economic and social progress will be turned to the past and our daily lives completely transformed.

Electrical power has become universal. Thousands of applications of electricity such as lighting, electrochemistry and electrometallurgy are longstanding and unquestionable.

With the appearance of the electrical motor, power cables replaced transmission shafts, gear wheels, belts and pulleys1 in the 19-th century workshops. And in the home a whole range of various time and labour saving appliances have become a part of our everyday lives.

Other devices are based on specific properties of electricity: electrostatics in the case of photocopying machine and electromagnetism in the case of radar and television. These applications have made electricity most widely used.

The first industrial application was in the silver workshops in Paris. The generator – a new compact source of electricity – was also developed there. The generator replaced the batteries and other devices that had been used before.

Electric lighting came into wide use at the end of the last century with the development of the electric lamp by Thomas Edison. Then the transformer was invented, the first electric lines and networks were set up, dynamos and induction motors were designed.

Since the beginning of the 20th century the successful development of electricity has begun throughout the industrial world. The consumption of electricity has doubled every ten years.

Today consumption of electricity per capita is an indicator of the state of development and economic health of a nation. Electricity has replaced other sources of energy as it has been realized that it offers improved service and reduced cost.

One of the greatest advantages of electricity is that it is clean, easily-regulated and generates no by-products. Applications of electricity now cover all fields of human activity from house washing machines to the latest laser devices. Electricity is the efficient source of some of the most recent technological advances such as the laser and electron beams. Truly electricity provides mankind with the energy of the future.

PRACTICAL UNITS

The three practical units, the ohm, ampere, and volt, provide standards for comparison. They are defined as follows –

The ohm is the first primary unit, and the international ohm is defined as the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14.4521 gm. in mass, of uniform cross-sectional area and of length 106.300 cm.

The ampere is the second primary unit. The international ampere is the unvarying electric current which, when passed through a solution of nitrate of silver in water, in accordance with a specification, deposits silver at the rate of 0.00111800 gm. per second.

The volt is the third primary unit and is the electric pressure which, when applied steadily to a conductor whose resistance is one international ohm, will produce a current of one international ampere. Further, the international watt is the energy expended per second by an unvarying electric current of one international ampere under an electric pressure of one international volt.

In addition to the practical construction of the ohm as defined above it may be derived in absolute measure as it has the dimensions of a velocity.

The original c.g.s. ampere was based on the magnetic effect of a current instead of the present electro-chemical effect.

M.K.S. UNITS

An alternative absolute system is based on the dimensions metre, kilogramme, and second. This is only one of many possible alternatives containing any multiple or sub-multiple of the metre and the gramme. It has the advantage over the c.g.s. system of simpler identity between the absolute and the practical units in that it removes the powers of 10.

For the practical applications of the m.k.s. units a fourth unit is required in order to define all the practical units. This has been taken to be the unit of resistance, leading to the expression M.K.S. Ω units. But the present agreed fourth unit is the term μ_0, the permeability of free space, this being more fundamental. This applies of course to the m.k.s. system of electromagnetic units, providing M.K.S. μ units. Electrostatic units are not used with the m.k.s. system.

If μ_0 is taken to be unity in the c.g.s. system it becomes 10^{-7} in the m.k.s. system (but if rationalized it is $4\pi\times10^{-7}$).

ELECTRIC CURRENT

Ever since Volta first produced a source of continuous current, men of science have been forming theories on this subject. For some time they could see no real difference between the newly-discovered phenomenon and the former understanding of static charges. Then the famous French scientist Ampere (after whom the unit of current was named) determined the difference between the current and the static charges. In addition to it, Ampere gave the current direction: he supposed the current to flow from the positive pole of the source round the circuit and back again to the negative pole.

We consider Ampere to be right in his first statement but he was certainly wrong in the second, as to the direction of the current. The student is certain to remember that the flow of current is in a direction opposite to what he thought.

Let us turn our attention now to the electric current itself. The current which flows along wires consists of moving electrons. What can we say about the electron? We know the electron to be a minute particle having an electric charge. We also know that that charge is negative. As these minute charges travel along a wire, that wire is said to carry an electric current.

In addition to travelling through solids, however, the electric current can flow through liquids as well and even through gases. In both cases it produces some most important effects to meet industrial requirements.

Some liquids, such as melted metals for example, conduct current without any change to themselves. Others, called electrolytes, are found to change greatly when the current passes through them.

When the electrons flow in one direction only, the current is known to be d. c., that is, direct current. The simplest source of power for the direct current is a battery, for a battery pushes the electrons in the same direction all the time (i.e., from the negatively charged terminal to the positively charged terminal).

The letters a.c. stand for alternating current. The current under consideration flows first in one direction and then in the opposite one, The a.c. used for power and lighting purposes is assumed to go through 50 cycles in one second. One of the great advantages of a.c. is the ease with which power at low voltage can be changed into an almost similar amount of power at high voltage and vice versa. Hence, on the one hand alternating voltage is increased when it is necessary for long-distance transmission and, on the other hand, one can decrease it to meet industrial requirements as well as to operate various devices at home.

Although there are numerous cases when d.c. is required, at least 90 per cent of electrical energy to be generated at present is a.c. In fact, it finds wide application for lighting, heating, industrial, and some other purposes.

One cannot help mentioning here that Yablochkov, Russian scientist and inventor, was the first to apply a.c. in practice.

TYPES OF ELECTRIC CURRENT

An electric current may be produced in a variety of ways, and from a number of different types of apparatus, e.g. an accumulator, a d.c. or an a.c. generator, or a thermionic valve. Whatever the source of origin, the electric current is fundamentally the same in all cases, but the manner in which it varies with time may be very different. This is shown by the graph of the current plotted against time as a base, and a number of examples are illustrated in Fig. 1.

(a) represents a steady direct current (D.C.) of unvarying magnitude, such as is obtained from an accumulator.

(b) represents a D.C. obtained from a d.c. generator, and consists of a steady D.C. superimposed on which is a uniform ripple of relatively high frequency, due to the commutator of the d.c. generator. As the armature rotates the commutator segments come under the brush in rapid succession and produce a ripple in the voltage which is reproduced in the current.

(c) represents a pulsating current varying periodically between maximum and minimum limits. It may be produced by adding a D.C. to an A.C. or vice versa. The d.c. component must be the larger if the current is to remain unidirectional. All the first three types, of current are unidirectional, i.e. they flow in one direction only.

(d) represents a pure alternating current (A.C.). The current flows first in one direction and then in the other in a periodic manner, the time of each alternation being constant. In the ideal case the current varies with time according to a sine law, when it is said to be sinusoidal. Considering the time of a complete cycle of current (a positive half-wave plus a negative half-wave) as equal to 360°, the instantaneous values of the current are proportional to the sine of the angle measured from the zero point where the current is about to rise in the positive direction*.

(e) represents a type of A.C. with a different wave form. Such an A.C. is said to have a peaked wave form, the term being self explanatory.

(f) represents an A.C. with yet another different wave form. Such an A.C. is said to have a flat-topped wave form, the term again being self-explanatory. Both this and the previous example represent cases of A.C. having non-sinusoidal wave forms.

(g) represents an example of an oscillating current, and is similar in shape to (d) except that it has a much higher frequency. An oscillating current is usually regarded as one having a frequency determined by the constants of the circuit, whereas an alternating current has a frequency determined by the apparatus supplying the circuit.

(h) represents another type of oscillating current which is known as damped. The current again has a constant frequency, but its amplitude is damped, i.e. it dies down, after which it is brought back to its original value.

(i) represents yet another type of oscillating current, this time known as a modulated current. The amplitude varies rhythmically between maximum and minimum values. It may even die down to zero.

(j) The next three examples represent various types of transient currents. These transient currents usually die away extremely rapidly, and times** are generally measured in microseconds. The first example shows a current dying away to zero, and is an example of a unidirectional transient. Theoretically it takes an infinite time to reach absolute zero.

(k) represents a simple a.c. transient. The current gradually dies down to zero as in the previous case, but this time it is an A.C. that is dying away.

(l) represents a peculiar, but not uncommon, type of a.c. transient. The current is initially unidirectional, but it gradually becomes an ordinary A.C. The positive half-waves die away much more rapidly than the negative half-waves grow, so that the final amplitude is very much reduced.

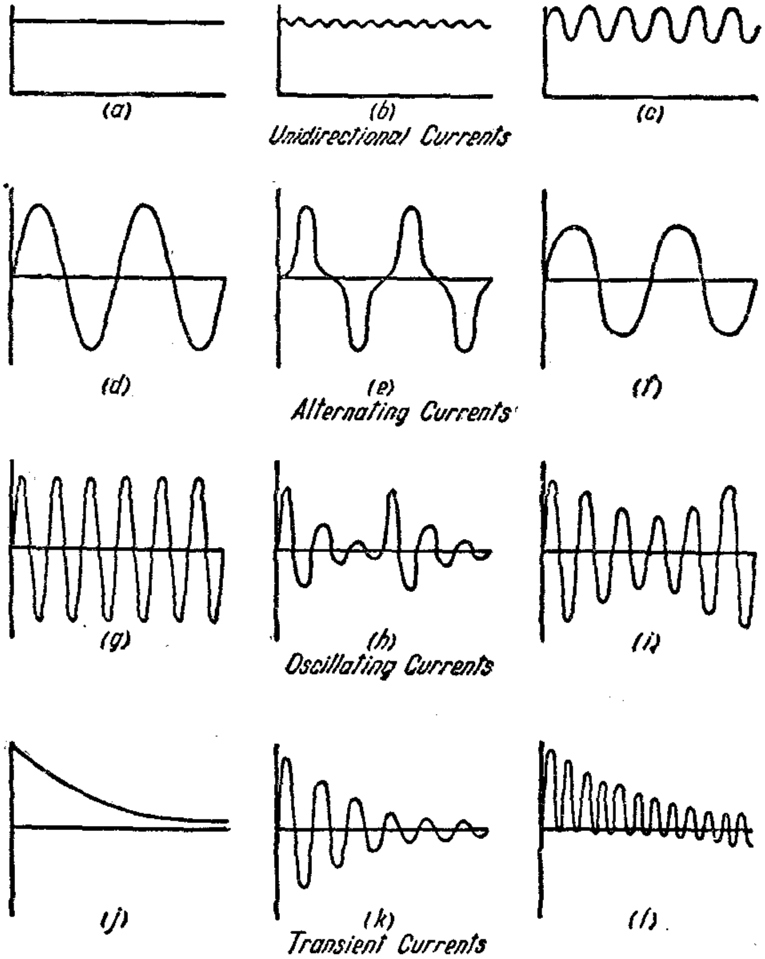

Fig. 1. Types of Electric Current

The above examples do not represent all the types of current encountered, but they serve as illustrations of what may be expected. It will be observed that in all the above cases the current consists of either or both unidirectional and alternating components***. In modern electrical engineering alternating currents play a predominant part, so that a knowledge of the a.c. circuit is of basic importance.

* where the current is about to rise in the positive direction где ток должен начать возрастать в положительном направлении; (to) be about to *собираться* (делать ч. л.)

** times зд. *периоды затухания*

*** in all the above cases the current consists of either or both unidirectional and alternating components во всех вышеуказанных случаях ток состоит или из тока одного направления, или из знаков переменного тока, или из того и другого вместе. Above в функции определения переводится «вышеуказанный, вышеупомянутый». Местоимение either здесь имеет значение *любой*, *один из двух*, но не *оба*.

DIFFERENCE BETWEEN A.C. AND D.C.

A direct current (D.C.) flows continuously through a conducting circuit in one direction only, although it may not be steady so far as magnitude is concerned. It is unidirectional in character. An alternating current (A.C.), on the other hand, continually reverses in direction, as its name implies. Starting from zero, it grows in one direction, reaches a maximum, dies down to zero again, after which it rises in the opposite direction, reaches a maximum, again dying down to zero. It is thus continually changing in magnitude as well as direction, and this continual change causes certain effects of far-reaching importance.

It can be shown that high voltages are desirable for the economic transmission of a given amount of electric power. Take, for example, the transmission of 1000 kW. If the transmission voltage is 100 volts the current must be 10,000 amperes, but if the transmission voltage is 10,000 volts the current is only 100 amperes. The cross-section of the cables transmitting the power is determined by the current to be carried, and so in the former case the cables would need to be very much larger than in the latter case. It is true that the high-voltage cable would need to have more insulation, but even so, it would be very much cheaper than the larger low-voltage cable. A high voltage is therefore essential for the economic transmission of electric power. Again, a.c. generators can be designed and built for much higher voltages than can d.c. generators, the voltage of the latter being limited by the problem of sparking at the commutator, a component which is absent in the a.c. generator. Then there is the most important factor that it is easy to transform a.c. power from one voltage to another by means of the transformer, an operation that is denied to the d.c. system. The transformer also enables the voltage to be stepped down at the receiving end of the transmission line to values which can readily be used by the various consumers. If necessary, it can be converted to the d.c. form for actual use, although this is not often necessary. There are certain processes for which D.C. is either essential or at any rate desirable but the utilization of electric power in the a.c. form is growing steadily. At the present day, by far the greater part* of the generation, transmission, and utilization of electric power is carried out by means of A.C.

* by far the greater part значительно большая часть; by far употребляется перед сравнительной степенью прилагательного для усиления его значения

ELECTRIC CIRCUIT

The electric circuit is the subject to be dealt with in the present article. But what does the above term really mean? We know the circuit to be a complete path which carries the current from the source of supply to the load and then carries it again from the load back to the source.

The purpose of the electrical source is to produce the necessary electromotive force required for the flow of current through the circuit*

The path along which the electrons travel must be complete otherwise no electric power can be supplied from the source to the load. Thus we close the circuit when we switch on our electric lamp.

If the circuit is broken or, as we generally say "opened" anywhere, the current is known to stop everywhere. Hence, we break the circuit when we switch off our electrical devices. Generally speaking, the current may pass through solid conductors, liquids, gases, vacuum, or any combination of these. It may flow in turn over transmission lines from the power-stations through transformers, cables and switches, through lamps, heaters, motors and so on.

There are various kinds of electric circuits such as: open circuits, closed circuits, series circuits, parallel circuits and short circuits.

To understand the difference between the following circuit connections is not difficult at all. When electrical devices are connected so that the current flows from one device to another, they are said to be connected in series. Under such conditions the current flow is the same in all parts of the circuit, as there is only a single path along which it may flow. The electrical bell circuit is considered to be a typical example of a series circuit. The parallel circuit provides two or more paths for the passage of current. The circuit is divided in such a way that part of the current flows through one path, and part through another. The lamps in your room and your house are generally connected in parallel.

Now we shall turn our attention to the short circuit sometimes called "the short". The short circuit is produced when the current is allowed to return to the source of supply without control and without doing the work that we want it to do. The short circuit often results from cable fault or wire fault. Under certain conditions, the short may cause fire because the current flows where it was not supposed to flow. If the current flow is too great a fuse is to be used as a safety device to stop the current flow.

The fuse must be placed in every circuit where there is a danger of overloading the line. Then all the current to be sent will pass through the fuse.

When a short circuit or an overload causes more current to flow than the carrying capacity of the wire, the wire becomes hot and sets fire to the insulation. If the flow of current is greater than the carrying capacity of the fuse, the fuse melts and opens the circuit.

A simple electric circuit is illustrated in Fig. 3. In (his figure a 4-cell battery has been used, the switch being in an open position. If the switch is in a closed position, the current will flow around the circuit in the direction shown by the arrows.

TERMS AND DEFINITIONS

In the following paragraphs the terms commonly used to distinguish between the various properties, or ways measuring the properties of alternating current are described.

Cycle and Period.– The complete series of changes consisting of the growth and decay of the voltage or current in one direction, together with its growth and decay in the reverse direction, is called one cycle. A voltage or current that is reproduced at equal intervals is said to be periodic, and the minimum time interval elapsing before the same instantaneous value recurs is called the periodic time or the period.

Frequency.– The number of complete cycles per second through which a voltage or current passes is called the frequency. It is always expressed in cycles per second, the reciprocal of this number being the periodic time.

Frequencies are now standardized for power purposes in the principal countries of the world, the standard for Great Britain being 50 cycles per second, while the U.S.A. has adopted 60 cycles per second.

Wave Form. – The shape of the graph of the voltage or current, when plotted against time as a base, is called the wave form or wave shape. The ideal aimed at is that of the sine wave*, i.e. the graph has the same shape as the graph of a sine function in mathematics. The sine goes through 360° in a complete cycle, and so the time scale on the wave form of a voltage or current is usually represented in degrees, 360° being considered the equivalent of the time corresponding to 1 cycle, or the periodic time. Since these degrees may not always coincide with the geometrical degrees through which the rotating member of a machine has been rotated, they are called electrical degrees, in order to distinguish them from geometrical degrees.

One cycle is thus regarded as the equivalent of 360°, and 180° is considered as a half-cycle, i.e. the duration of the voltage or current in one direction only.

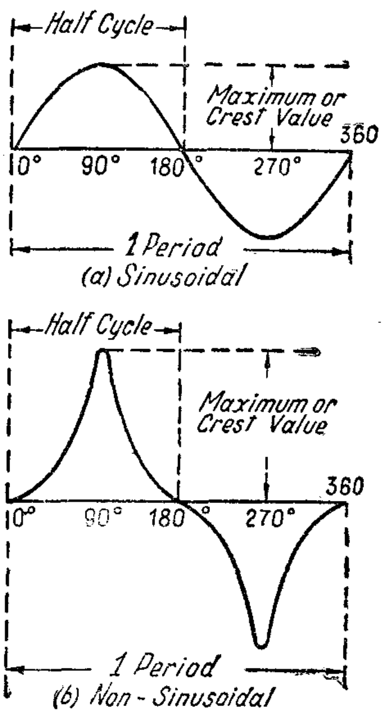

Fig. 2. Examples of Wave Form.

Fig. 2(a) shows the ideal wave form, which is that of the sine wave, while Fig. 2(b) shows a non-sinusoidal wave form. The possible number of non-sinusoidal wave forms is infinity, some being close approximations to the ideal sine shape, while others are widely dissimilar.

Phase and Phase Difference. – During the interval of time necessary for a current to pass through one complete cycle, it passes through many phases. In fact it has a different phase for each different interval of time. Consider the analogous case of the phases of the moon. Starting from the time of new moon the, moon passes through its various phases, measured by its age from the time of the new moon, up to full moon, and then onwards through the various stages of the waning moon. Similarly an alternating current goes through various phases, starting from zero, rising up to maximum, and dying down again to zero. In the A.C. case, however, this comprises only half a cycle, for the whole series of values are then repeated in the opposite (negative) direction. Other electrical quantities, such as voltage, power, etc., in addition to current go through various phases from 0° to 360°; indeed all quantities which vary in a periodic manner do so. When two voltages or two currents are considered together, however, or when a voltage and current are considered simultaneously, the frequency being the same, they may not pass through the same phase at the same instant of time. For example, two currents may be such that, although their frequency may be the same, their phase at a particular instant of time may be different. One may pass through its maximum value at the instant when the other has a zero value, or some other value not its maximum value; the two currents, etc., are then said to have a phase difference, this being quoted in degrees. I one current has its maximum value at the same time that the other is zero, the two currents are said to be in quadrature; they have a phase difference of 90°. Phase difference, because it is constant in a circuit where steady conditions obtain, is much more important in a.c. work than the actual phase which varies from instant to instant.

Phase difference is illustrated in Fig. 3, where two currents are shown not in phase. The phase difference is measured by the distance between the points where the two graphs cross the base line in the same direction. This distance is measured in electrical degrees, the scale being obtained by considering the distance corresponding to one complete cycle as 360°. The current that is ahead in phase is said to lead the other current, while this current is said to lag behind the first current. Similarly, when considering two voltages, one is said to lead and the other to lag. Again, a voltage may lead the current that it produces, the current lagging behind the voltage.

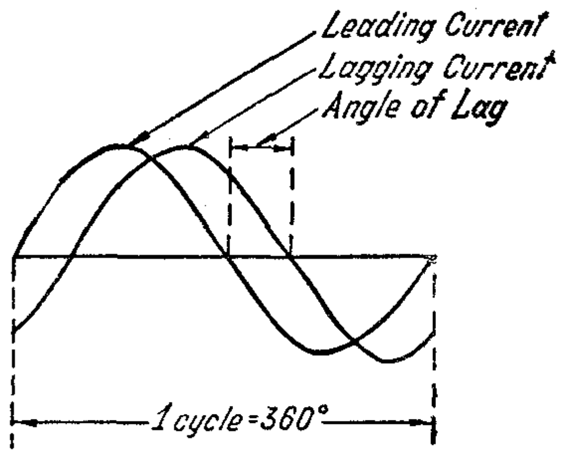

Fig. 3. Illustrating Phase Difference

Maximum and Average Values.– An alternating current varies in strength from instant to instant, and reaches a maximum value twice in every cycle, once in each direction. This maximum value is called the crest value. (See Fig. 2).

The average value, taken throughout a complete cycle, is equal to zero, since there is as much current flowing in one direction as there is flowing, in the other direction. Considering a half-cycle, however, the average value has a definite positive value. This can be evaluated by measuring the lengths of a number of equidistant ordinates and taking their average value. In the case of a sine wave, this average value is found to be equal to $\frac{2}{\pi}$ or 0.687 times the maximum value but is not, however, the value read on an ordinary ammeter, nor is it the value commonly used to denominate the value of an A.C.

** the ideal aimed at is that of the sine wave идеалом, к которому стремятся, является синусоидальная волна; aimed at = which is aimed at; that – заменитель ранее упомянутого существительного

PRODUCTION OF THREE-PHASE CURRENTS

In an ordinary a. c. circuit the current goes through all its phases in succession, but at any particular instant the current has only one phase. In the three-phase system there are three circuits, and the currents in these have three different phases at the same instant of time. The phase difference between any two of these three phases is 120°.

In an ordinary a. c. circuit the current goes through all its phases in succession, but at any particular instant the current has only one phase. In the three-phase system there are three circuits, and the currents in these have three different phases at the same instant of time. The phase difference between any two of these three phases is 120°.

Imagine an armature core to be rotated in a counter-clockwise direction between the two poles of a magnetic field excited by D. C., as shown in |Fig. 5. The two conductors A and A' are connected in series to form a turn, the front end of the conductor A being considered as the front end of the turn, and the front end of the conductor A' being considered as the rear end. As the armature core is rotated, a sinusoidal e. m. f. is induced in the turn AA'. Next consider the turn BB', where B is regarded as the front end and B' the rear end. A sinusoidal e. m. f. will also be induced in this turn, but it does not reach its maximum value in the positive direction until the core has been rotated through 120°. In other words, this e. m. f. although having the same maximum and r. m. s. value as that induced in the turn AA', is behind it in phase by 120°. Finally, consider the turn CC' in the same way. The induced e. m. f. again has the same maximum and r. m. s. value, but it is a further 120° behind in phase*. Following on this, yet another 120° behind in phase, the first turn AA' induces an e. m. f. which is 3×120° = 360° behind the original e. m. f. induced in AA'. Putting this another way, the turn AA' is now beginning to induce the second cycle of e. m. f. The three e. m. f. s induced in the three turns are represented graphically in Fig. 6, where it is seen that there is a phase difference of 120°, or one-third of a cycle, between the e. m. f.'s of each pair. If each of these turns is connected to the ends of a resistance, three currents will be obtained, also having a mutual phase difference of 120°, these currents being called three-phase currents.

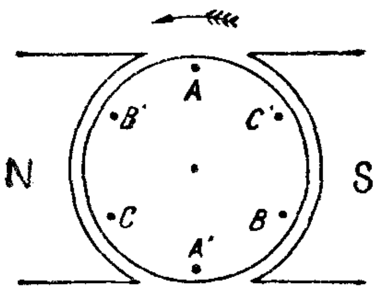

Fig. 5. Coils arranged to induce Three-Phase E.M.F.'s

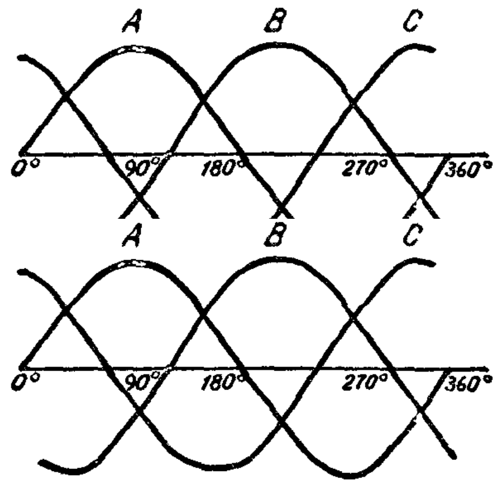

Fig.6. Three-Phase E. M. F.'s or Currents.

In practice it is usual to arrange the armature conductors on the stationary element of the machine, now called the stator, the d. c. excited field forming the rotating element, or rotor. Each winding also is made to consist of many turns. It does not matter, however, whether the conductors cut the magnetic flux, or the magnetic flux cuts the conductors; the action is the same.

* but it is a further 120° behind in phase но она (эдс) еще на 120° отстает по фазе

TRANSMISSION OF THREE-PHASE POWER

The three windings discussed above can be made to supply three individual circuits, when all six ends must be used. It is possible, however, to link the three circuits electrically with the result that the number of conductors necessary for the transmission of the power is reduced.

In the first instance it is possible to effect an economy by using a common return, this being permissible since it does not disturb the electrical arrangement. This implies that the three rear ends of the turns, A', B', and C' must all be joined, together with the three rear ends of the three resistances used as loads. This arrangement is illustrated in Fig. 7 which shows the three generator windings connected together at one end, the other ends being connected to three conductors for the purpose of transmitting the power. The return conductor carries the vector sum of these three currents back to the common junction of the three generator windings.

If the three e. m. f. s are all equal and the three load resistances are also all equal, the three currents will also be all equal and will have a phase difference of 120° from one another. In these circumstances the system is said to be balanced.

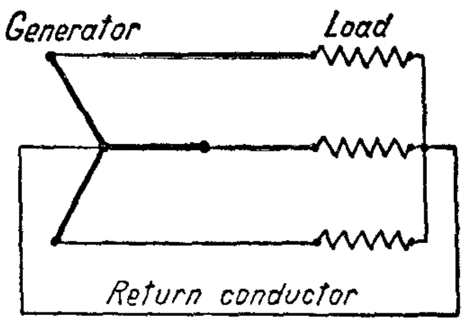

Fig. 7. Transmission of Three-Phase Power by Four Conductors

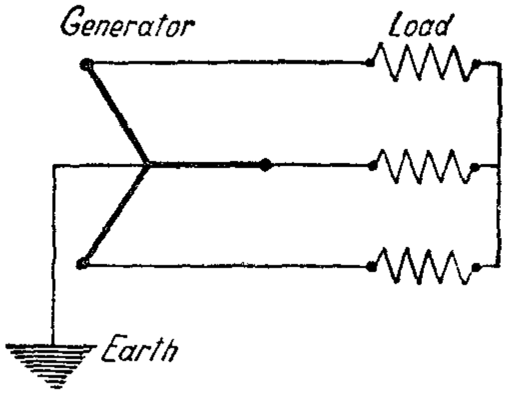

Fig. 8. Transmission of Three- Phase Power by Three Conductors

Three-Wire Transmission. – In a balanced three-phase system the three currents are equal and can be represented by the graphs shown in Fig. 6, substituting current for e. m. f. The resultant current in the tourth (return) conductor is, at any instant, the algebraic sum of the three line currents and, on examination of the graphs, it is found that this algebraic sum is zero at every instant. The fourth (return) conductor thus carries no current and it can be omitted. The connections now take the form shown in Fig. 8, three conductors only being employed.

Each conductor now acts in turn as the return for the other two. This can be checked from Fig. 6, where it is seen that the reverse current in one phase is always equal to the forward current in the other two. (At certain instants, two conductors act as the return for the forward current in the remaining conductor). It is also general practice to earth the system at one point, this being done conveniently at the generator common junction as shown in Fig. 8.

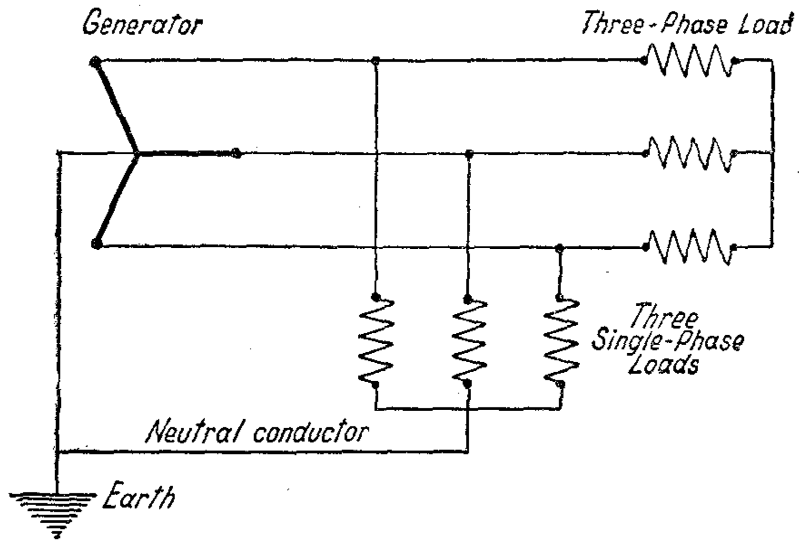

Fig. 9. Connections for Three-Phase Four-wire System

Three-Phase Four-Wire System.– This is a system of connections which permits the employment of a three-phase load and three single-phase loads simultaneously, as shown in Fig. 9. It re-introduces the fourth conductor to act as a common return for the three singlephase loads, this conductor being called the neutral. The other three conductors are called the line conductors. The system is earthed as before, by connecting the neutral conductor to an earthed plate or other earthing connection.

Colour Scheme.– For purposes of standardization it is now the general practice to mark each particular phase by a distinctive colour. The three phases are coloured red, white (or yellow), and blue, respectively, while the neutral conductor is coloured green.

ELECTRICAL MEASUREMENTS

The measurement of any physical quantity applies a determination of its magnitude in terms of some appropriate unit. It follows, therefore, that before we can measure we must decide upon a system of units which will be convenient for the purpose. In the case of simple fundamental quantities such as length, mass, or time, the units themselves are simple.

Electrical and magnetic quantities are, however, much less simple than length, mass, or time, and cannot be measured directly by comparison with a material standard. The units in which we express these quantities have to be defined in terms of their observable, effects obtained in experimental work, e. g. the weight of silver deposited in one second by a current when it is passed through a solution of silver nitrate is a measure of the magnitude of this current.

Electrical measurements can be classified broadly as either absolute measurements, or secondary measurements, but we need concern ourselves very little with the first class because such measurements are rarely undertaken and. generally speaking, are used only for periodic checks upon the accuracy of primary standards. They are or interest only to the specialist, the very large majority of the measurements made in practice being secondary, or comparison, measurements.

INSTRUMENTS AND METERS

Component Parts of Indicating and Recording Instruments Classification.– Electrical measuring instruments can be divided into three classes: *indicating instruments*, *recording instruments* and *integrating instruments*.

Indicating instruments, such as ammeters, voltmeters and wattmeters, constitute the largest of the three classes. These are fitted with a pointer which moves over a fixed scale and their characteristic is that they give an immediate indication of the value of the current, voltage or other quantity being measured. Such an instrument might therefore be compared with, say, a weighing machine or a barometer, giving an immediate reading of the weight or pressure existing at any instant, but making no permanent record of such a measurement.

Recording instruments, or graphers, as they are sometimes called, instead of being fitted with a pointer and scale, carry a pencil or pen, which presses on to a travelling ribbon of paper, and thus makes a continuous chart or record of the values measured. Such an instrument could be compared with the recording barometer often exhibited in an instrument maker's window. It will be noted that these two types do not differ in principle, since they are both used to measure the same kinds of things; but in the one case the indication is momentary and must be read by an observer on the spot, whilst in the other case the values are recorded on a chart for future observation and reference.

The third group, consisting of **integrating instruments** or electricity supply meters, differs fundamentally from the other two groups, since instead of indicating or recording, these instruments add up the total amount consumed over any given period. Thus, instead of reading, say, the current or the power flowing at any instant, they measure the product of current and time (in ampere-hours) or of power and time (in watt-hours), and so add up the electrical quantity or energy consumed.

An integrating instrument is, therefore, like the gas meter, which registers the quantity of gas consumed. Instead of a pointer and scale with a limited arc of movement, they are usually made to revolve and carry a train of gearing and a register which counts the number of revolutions made. In such instruments, the rate of revolution being proportional to the current (in an ampere-hour meter) or to the power (in a watt-hour meter), the total number of revolutions is proportional to the ampere-hours or watt-hours respectively.

All indicating instruments have three essential features: an operating force or mechanism, a controlling force or mechanism, and a damping force or mechanism. It must be realized that all measurement is comparison, and just as a length can be measured by putting a foot rule against it, or a weight can be measured by balancing it against another weight, so an electrical effect can only be measured by allowing it to act against some known force or control. Thus, the process of electrical measurement can be said to consist of a "tug of war"* between two opposing forces – the operating force, or torque, generated by the electricity which is being measured, and the controlling force, or torque, which opposes it. When the instrument comes to rest the pointer indicates the position of stability reached by these two opposite pulls. Although it does not enter into the actual measurement by influencing this position of stability, damping is essential to bring the moving system of the instrument to rest in a reasonably short time. When an electric current flows, it gives rise to various effects – heating, electrostatic, electro-magnetic and chemical, and any one of these effects can be utilized to furnish the operating force of a measuring instrument.

* "tug of war"–спортивная игра – «перетягивание на канате»

AMMETERS AND VOLTMETERS

Instrument Connections

The difference between an ammeter and a voltmeter seems to be fundamental, since the former is connected in series with the circuit and reads the current, whilst the latter is connected across the circuit and reads the voltage. In practice, however, it will be found that practically every voltmeter except the electrostatic type is operated by a flow of current through the instrument, so that the voltmeter is really a form of ammeter, but reading a very small current at a relatively high voltage.

As an example, take the moving iron type of mechanism which consists of a fixed coil of wire magnetizing a small piece of iron on the spindle of the instrument. In order to obtain full deflection it may be necessary for the coil to have an excitation* of 300 ampere-turns, and if the instrument is to be an ammeter to read up to 10 amperes, this could be obtained by winding the bobbin with thirty turns of a fairly stout wire. The same mechanism could, however, be employed as a voltmeter by winding it with a very large number of turns of fine wire, so designed that the maximum voltage to be measured when applied to the coil sends sufficient current through it to provide the correct number of ampere-turns.

* for the coil to have an excitation чтобы катушка имела возбуждение; зд. инфинитивный оборот с предлогом for.

Types of Ammeters and Voltmeters

In order to produce the necessary deflecting torque for the operation of ammeters and voltmeters the various effects of electric current and of potential – the heating effect, electrostatic effect, magnetic effect, and electro-magnetic induction effect – are used leading to a number of different types of instrument. The resulting instruments are called: (a) hot wire, (b) electrostatic, (c) moving iron, (d) moving coil, and (e) induction. They are dealt with in some detail in succeeding pages where their advantages, disadvantages, and specialized characteristics are given. By way of introduction*, however, it may be well to point out that the various types are usable on both d. c. and a. c. circuits with two exceptions, namely, the permanent-magnet, moving-coil instrument which can be used only with d. c., and the induction instruments which are limited to a. c. operation. For general purposes the moving-iron instruments are by far the most commonly used, while for d. c. work the permanent-magnet, moving-coil instrument is the best, being specially suitable for use with shunts and multipliers for multi-range purposes. The other types are uncommon for general work, although each has advantages under certain conditions. Thus the order in which the instruments are described below is not that of relative importance, but merely such as to fit in with the general arrangement of the presentation.

Hot Wire.– When an electric current flows along a conductor the latter becomes heated, the heating effect being simple to use for measurement purposes. The heat produced per second in a conductor of any given resistance is proportional to the square of the current, and the conductor will, therefore, be heated up to the point at which it radiates each second all the heat which the current is producing. Its temperature rise above the surroundings will then be proportional to the square of the current flowing, and it is only necessary to measure this temperature rise in order to get a measure of the amount of the current.

The simplest way of measuring the temperature rise is by means of the linear expansion which it causes in the wire carrying the current, and hot-wire instruments work on this principle. Unfortunately the expansion is extremely slight, being of the order of one hundred thousandth of the length for each degree centigrade, and it therefore becomes necessary to magnify the movement many times before transmitting it to the pointer of the instrument. This complicates what would otherwise be a very simple type of mechanism, and it also introduces errors due to the stretch of the various wires employed or to the interplay of the magnifying mechanism. Other errors may be introduced due to the expansion of the baseplate of the instrument and for these reasons the hot-wire instrument frequently exhibits a zero error and is usually only of second-grade accuracy.

Fig. 10 shows diagrammatically a hot-wire instrument employing what is called the double-sag method of magnifying the expansion movement. The current to be measured, or some definite fraction of it, passes through the expansion wire E, which is made of platinum-iridium or platinum-silver, either of which alloys will stand a high temperature without oxidization. When this wire is heated and expands, its sag is taken up by a phosphor bronze wire P, and the sag in this is taken up by a silk fibre F, which is kept taut by a small spring S. This silk fibre passes round a small pulley mounted on the instrument spindle and a very minute expansion in the hot wire E causes a considerable movement of the spindle, and is shown by the pointer mounted on it.

When the instrument is required to be a voltmeter the expansion wire is connected in series with a high resistance whose value will depend upon the voltage range which is required. The current necessary to operate the hot wire is usually of the order 0.1 to 0.2 amp., and as the resistance of the wire itself is only 10 ohms or so, it will be seen that except on very low ranges the added resistance absorbs the greater part of the voltage applied to the instrument terminals. Provided this added resistance does not vary with temperature, the current flowing through the expansion wire will be directly proportional to the applied voltage and the expansion will, therefore, be proportional to the square of the voltage.

When the instrument is to be an ammeter, the expansion wire can be made somewhat thicker, but if too stout, the instrument will be sluggish in action, as the wire will take an appreciable time to reach its final temperature. The sizes used in practice are therefore such as to require only a fraction of an ampere to raise them to their full temperature. Hence, when a bigger current than this is to be measured, the hot wire has to be shunted with a resistance of a lower value, and this reduces the accuracy of the instrument. As explained previously, the shunt must be designed so that the current through the hot wire bears a constant ratio to the total flowing through the instrument so that the expansion obtained will be proportional to this current squared. The use of such a shunt is not very satisfactory, however, since the resistance of the hot wire will vary somewhat with different currents, while that of the shunt will remain constant.

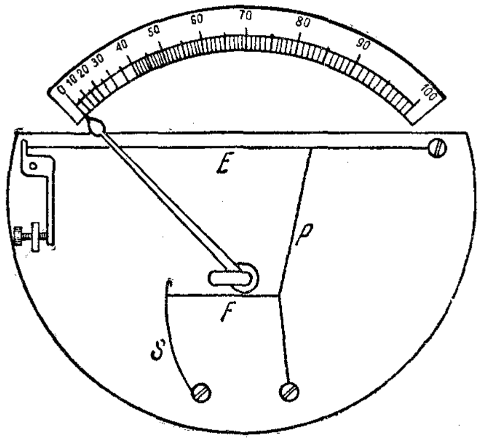

Fig. 10.

It will be seen that both in ammeters and voltmeters, the expansion of the hot wire is proportional to the square of the quantity being measured, and although the magnification system modifies this effect somewhat, the result is always a scale very crowded at the beginning and very open at the end** (see Fig. 10). This may sometimes be a serious disadvantage, since small values cannot be read on a large range meter. On the other hand, the hot-wire type is particularly suitable for measuring alternating quantities, since the value of a current which is alternating is defined as that value which, if flowing continuously, would produce an equal amount of heating. Hence the hot-wire instrument, or in fact any type obeying what is called a "square law", will read the same for alternating as for direct currents, whatever the shape of the alternating wave. This is very useful when measurements are to be made in circuits in which the current or voltage wave-form departs considerably from the ideal sinusoidal shape.

Moving-iron Instrument. The electro-magnetic effect of a current is the one chiefly made use of for measurement purpose. Moving-iron instruments employ this effect. In principle the moving-iron instrument consists of a fixed coil of wire carrying the current which magnetizes a small piece of soft iron mounted on the instrument spindle. In construction there are two varieties – the repulsion type having two pieces of iron, and the attraction type having only one. In the attraction type of instrument illustrated in the sketches in Fig. 11 the bobbin C carrying the wire is oblong instead of circular and has only a narrow slot-shaped opening in its centre. A thin flat piece of soft iron, A, which is mounted on the instrument spindle is sucked into this slot by magnetic attraction when the current flows, the motion being opposed, in this case, by the weight W.

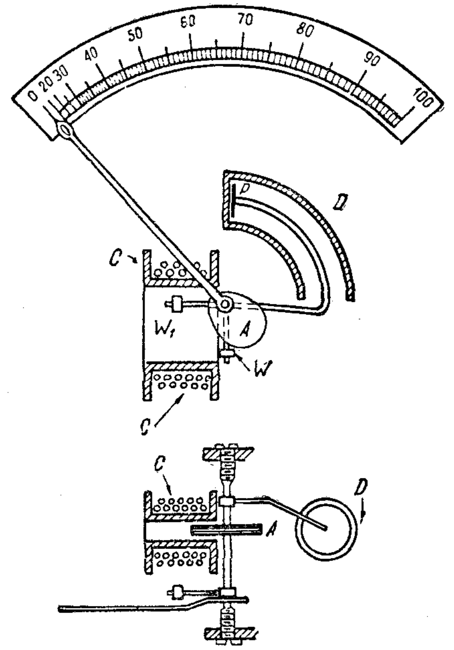

Fig. 11.

Either gravity or spring control can be employed on moving-iron instruments, and damping is usually by means of an air dash-pot. This latter is clearly shown in both of the above figures, where it takes the form of a light piston (P. Fig. 11), fixed to the spindle in such a way that it describes an arc of a circle within a curved cylinder whose walls it nearly touches.

Moving-Coil Instruments.– In moving-iron instruments the magnetic field is furnished by a fixed coil of wire carrying the current, and a piece of soft iron moves in this field. In the moving coil instruments now to be considered, this arrangement is reversed; the field is provided by a fixed permanent magnet, whilst a coil carrying the current moves within this constant field. Fig. 12. shows the general arrangement of a modern moving-coil permanent-magnet instrument. It will be seen that the instrument consists of a permanent magnet M, having two pole pieces, P. In between these pieces a circular iron core / is fixed by means of the bracket B, the latter being made of some non-magnetic material such as brass. This leaves a small annular air-gap in which the coil F is free to turn. This coil consists of a light aluminium framework carrying a number or turns of fine silk-insulated copper wire.

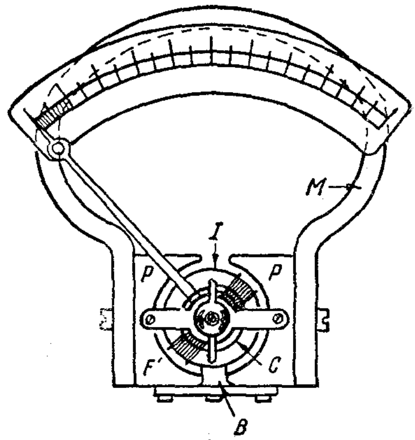

Fig. 12. Sketch of Moving-coil Instrument

When the current flows round this coil the latter tends to turn in the magnetic field provided by the permanent magnet, and its motion is opposed by the spiral hair spring C, of phosphor bronze, which also serves to lead the current into the coil. Usually there is a second control spring fitted at the other end of the instrument and wound in the opposite direction so as to neutralize temperature variations in the spring. This will then serve also to lead the current out of the moving coil, but in some cases a flexible metallic ligament serves this purpose and exerts no appreciable restriction on the movements of the coil.

* by way of introduction в качестве предисловия; by way of – составной предлог ради, с целью; через

** a scale very crowded at the beginning and very open at the end шкала очень сжата в начале и очень растянута в конце. В применении к делениям шкалы Past Participle от глагола (to) crowd (букв, тесниться, толпиться имеет значение сжатый, а прилагательное open –

растянутый).

DIRECT-CURRENT METERS

Functions of a Direct Current Meter.– A direct current meter is an instrument intended for the measurement of electrical quantity in a direct current circuit. There are two main classes of direct current meters, (1) ampere-hour meters and (11) watt-hour meters. An ampere-hour meter measures the product of the current in amperes flowing in a circuit and the time in hours during which the flow is maintained. A watt-hour meter measures the product of the power in watts and the time in hours during which the flow of power is maintained.

Direct Current Ampere-hour Meters.– Ampere-hour meters are used by electrical undertakings for measuring the supply of electricity to domestic and industrial, consumers. These undertakings are under a statutary obligation to maintain the voltage at consumers' terminals at a declared value within close limits; assuming that the supply voltage is maintained at the declared value, an ampere-hour meter can be calibrated to register in terms of kilowatt-hours at this voltage. This principle is accepted as satisfactory in most countries where the voltage at consumers' terminals is maintained within narrow limits of the declared voltage, and since direct current ampere-hour meters are, in general, more reliable and less costly than direct current watt-hour meters the practice has much in its favour.

In addition to the foregoing, ampere-hour meters are used for measuring the current consumption in battery charging, electro-deposition and other electrolytic or industrial processes and in some instances they exercise a controlling function over these operations. Many types of ampere-hour meter have been manufactured in the past, the most important being electrolytic meters and motor meters. Theoretically the former are capable of very accurate registration but in practice the working results are not so good as with motor meters, and the latter are preferred by most supply authorities.

GENERATING AN ELECTRIC CURRENT

The first method used in producing an electric current was chemical in nature. Credit for its discovery is given to an Italian physician named Aloisio Galvanl (17.47–1798). One day while engaged in dissecting a frog, Galvanl noticed the leg muscles contract whenever a nearby electric machine was in operation. Further investigation showed the same twitching effect to be obtained by simply connecting the nerve and muscle of the leg to dissimilar metals. But no such result was obtained if only one metal was used or if non-conductors were employed. There were obviously two possible sources of the phenomenon. Either the current was set up at the junction of the two metals or it was a property of the animal tissues. Galvani favoured the latter view and in 1791 announced his discovery, attributing the current to what he called "animal electricity" or as it came to be known, "galvanism". Galvani is an excellent example of a scientist who behaved most unscientifically with regard to a hypothesis which he himself had advanced. He became so prejudiced in favour of his animal magnetism theory that it was quite impossible for him to view objectively later evidence which definitely contradicted it and finally caused it to be discarded.

Another Italian, Alessandro Volta (1745–1827), a professor of physics in the University of Pavia, established the true source of the electric current. He demonstrated that it could be produced by the action of dissimilar metals without the presence of animal tissue of any sort.

In the course of his experiments in 1800 he developed the first electric battery, a device known as a voltaic pile. Although he tried a number of different materials he found that the best results were obtained when he used silver and zink as the two metals. The pile consisted of a Befits Of small discs of these and of cardboard, the latter having been soaked in a salt solution-Then he piled the discs up one on another in the order silver, zink, cardboard, and so forth, ending with zinc. By connecting wires to the top and bottom discs he was able to get continuous electric currents which were of substantial size.

All the essentials of a modern electric cell or battery were present in the voltaic pile. Developments since that time have been largely directed toward making cells more convenient to use and toward eliminating various undesirable chemical reactions.

THE DEVELOPMENT OF ELECTRIC MOTOR

The engine which could convert electric energy into mechanical power was already in existence. As early as 1822 Faraday outlined the way in which an electric motor could work: by placing a coil, or armature, between the poles of an electromagnet; when a current is made to How through the coil the electromagnetic force causes (I) it to rotate the reverse principle, in fact, of the generator.

The Russian physicist, Jacobi built several electric motors during the middle decades of the XIXth century. Jacobi even succeeded in running a small, battery-powered electric boat on the Neva river in St. Petersburg. All of them, however, came to the conclusion that the electric motor was a rather uneconomical machine so long as galvanic batteries were the only source of electricity. It did not occur to them that motors and generators could be made interchangeable.

In 1888, Professor Galileo FerYaris in Turm and Nikola Tesla – the pioneer of high-frequency engineering'–in America invented, independently and without knowing of each other's work, the induction motor. This machine, a most important but little recognized technical achievement, provides no less than two-thirds of all the motive power for the factories of the world, and much of modern industry could not do without (2) it. Known under the name of "squirrel-cage motor" – because (3) it resembles the wire cage in which squirrels used to be kept – (4) it has two circular rings made of copper or aluminium joined by a few dozen parallel bars of the same material, thus forming a cylindrical cage.

Although the induction motor has been improved a great deal and its power increased many times ever since its invention, there has never been any change of the underlying principle. One of its drawbacks was that its speed was constant and unchangeable.

Some years later a squirrel-cage motor with two-speeds –the most far-reaching innovation since the invention of the induction motor was developed. The speed change is achieved by modulating the pole-amplitude of the machine.

HEATING EFFECT OF AN ELECTRIC CURRENT

The production of heat is perhaps the most familiar among the principal effects of an electric current, either because of its development in the filaments of the electric lamps or, maybe, because of the possible danger from overloaded wires.

As you know, of course, a metal wire carrying a current will almost always be at a higher temperature than the temperature of that very wire unless it carries any current. It means that an electric current passing along a wire will heat that wire and may even cause it to become red-hot. Thus, the current can be detected by the heat developed provided it flows along the wire.

The reader is certain to remember that the heat produced per second depends both upon the resistance of the conductor and upon the amount of current carried through it. As a matter of fact, if some current flowed along a thin wire and then the same amount of current were sent through a thicker one, a different amount of heat would be developed in both wires. When the current is sent through the wire which is too thin to carry it freely, then more electric energy will be converted into heat than in the case of a thick wire conducting a small current.

Let us suppose now that a small current is flowing along a thick metal conductor. Under such conditions the only way to discover whether heat has been developed is to make use of a sensitive thermometer because the heating is too negligible to be detected by other means. If, however, our conductor were very thin while the current were large the amount of generated heat would be much greater than that produced in the thick wire. In fact, one could easily feel it. Thus, we see that the thinner the wire, the greater the developed heat. On the contrary, the larger the wire, the more negligible is the heat produced.

Needless to say, such heat is greatly desirable at times but at other times we must remove or, at least, decrease it as it represents a waste of useful energy. In case heat is developed in a transmission line, a generator or a motor, it is but a waste of electric energy and overheating is most undesirable and even dangerous. It is this waste that is generally called "heat loss" for it serves no useful purposes and does decrease efficiency. Nevertheless, one should not forget that the heat developed in the electric circuit is of great practical importance for heating, lighting and other purposes. Owing to it we are provided with a large number of appliances, such as: electric lamps that light our homes, greets and factories, electrical heaters that are widely used to meet industrial requirements, and a hundred and one other necessary and irreplaceable things which have been serving mankind for so many years.

In short, many of the invaluable electrical appliances without which life would seem strange and impossible at present can be utilized only because they transform electric energy into heat.

The production of heat by an electric current is called heating effect. One might also name its light effect provided the heat in the conductor be great enough to make it white-hot, so that it gives off light as well as heat. Take the filament of an electric lamp as an example. We know it to glow because of heat. By the way, were we able to look Inside a hot electric iron, we should see that its wires were glowing too. A similar statement could be applied as well to almost any electric heating device. All of them give off a little light and a lot of heat.

ELECTRICAL CONDUCTIVITY

The conductivity provided by conduction electrons will be determined by the number of electrons, and the ease of their movement in an applied electric field. The latter is described by their "mobility", which is the drift velocity of the carriers in cm/sec in a field of 1 volt/cm.

The temperature dependence of the conductivity of semiconductors is one of the most striking and characteristic of their properties. In Fig the behavior of some arsenic-doped samples of silicon is shown. The principle changes in the conductivity of a given sample, with temperature, result from changes in carrier concentration, although the mobilities also vary with temperature. At low temperatures the conductivity is low, because most of the carriers are frozen out on the donor centers. As the temperature rises, the degree of ionization of the donors increases, and the rising carrier concentration, results in a rapidly increasing conductivity. At around 100 the conductivity reaches a maximum, because of complete ionization of the donors. At considerably, higher temperature a very steep rise in the conductivity occurs, due to the onset of an appreciable intrinsic conduction. The drop in conductivity with rising temperatures, above 100 and below the intrinsic range, is in the region of saturation, i.e., the carrier concentration is constant and equal to Nd – Na. The reason for the drop lies in the temperature dependence of the mobility, In this range of temperatures, the mobility of the carriers decreases with rising temperatures due to "lattice scattering". The increasing thermal agitation of the lattice leads to a shorter distance for the carriers to travel between collisions with the lattice, and the carriers travel faster at higher temperatures, thus shortening the time between collisions; these factors both serve to decrease the mobility. Theoretically it is expected under certain assumptions, that in the lattice-scattering range the mobility should go as $T^{3}/^{2}$. Experimental results usually give a somewhat different exponent.

Any sample which shows little change in conductivity over a wide range of temperatures, is degenerated, because of the high concentration of arsenic, and of conduction electrons, in this sample. The behavior of p-type samples, doped with boron for example, is entirely similar to that shown for the n-type materials.

The lattice scattering mentioned above is one of the two principle mechanisms that limit mobility. At high impurity concentrations, or at temperatures low enough so that lattice scattering does not predominate, the mobility is limited by scattering by impurity centers. Ionized impurities are very much more effective than are neutral impurities. In the ionized impurity scattering region, varies as $T^{3}/^{2}$

THE P-N JUNCTION

If, within the same single crystal, there are adjacent regions of n- and p-type semiconductor, the resulting boundary is called a "- junction".

An n-type material contains mobile negative charges (conduction electrons), and an equal concentration of fixed positive charges (holes), and fixed negative charges (ionized acceptors). With the two regions in contact, the mobile electrons and holes might be expected to flow out of the n-and p-type regions, respectively, across the junction because of the concentration gradients for these species. On the other hand, this flow leaves the n-type region with a net of' positive charge, and the p-type region with a net of negative charge, thus establishing a field in a direction which opposes further flow. At equilibrium this field just balances the effect of the concentration gradient, as shown in the top of Fig. The net charges appear in the region immediately adjacent to the junction, and the field appears in this space-charge region.

The Fermi levels in the p and n regions must be equal at equilibrium, and this establishes the magnitude of the electrostatic potential difference between the two regions. Electrons and holes are constantly being generated in both regions and recombining at an equal rate. Some of the most energetic electrons in the n-region cross the potential barrier into the p-region and this forward flow of electrons is designated as If. At equilibrium, an equal number of electrons cross the junction in the opposite direction, the source of these in the p-region being thermal generation (I_g). Thus there is no net electron current across the junction, and likewise, no net hole current. If a positive potential is applied to thep-region, the effect is as shown in Fig. 11 (b). The potential barrier between the two regions is lowered, and the forward currents of both holes and electrons are greatly increased. The currents arising from the generation of minority carriers remain the same, and so there is a net flow of current across the junction, with contributions from both holes and electrons. This is called the condition of "forward bias". If the p-region is made negative with respect to the -region, the potential barrier becomes much higher, and If drops to a very low value for both kinds of carriers, A net current flows due to I_g, but it is much smaller than in the forward bias. It is seen therefore, that the p-n junction is a rectifier, i.e., the current passed varies in the magnitude depending on the polarity of the applied voltage. The ratio of forward to reverse current may be very high, e.g. in silicon rectification ratios of 10^6 can be achieved as shown in Fig.

The p-n junction illustrated is one in which the hole concentration on the p side is approximately the same as the electron concentration on the n side. This need not be the case, of course. If, say, the n side is much more heavily doped than the p side, the higher electron concentration gives rise to much higher electron currents across the junction than hole currents, in the condition of forward bias. The junction thus serves to inject electrons into the p-region.

SEMICONDUCTOR PRINCIPLE

The term "semiconductor" implies a definition, namely, that it is a material having an electrical conductivity inter mediate between that of metals and insulators. For many purposes this is a satisfactory definition. We recognize, how ever, that an enormous range of conductivities can meet this requirement. At room temperature, the conductivities characteristic of metals are of the order of 104 to 106 ohm-1 cm-1, while those of insulators may range from 10-22 to 10-10. The materials classed as semiconductors generally have conductivities from about 10-9 to 103. '

Materials which fall in this conductivity range, but which are largely ionic conductors, will not be of interest to us; it is electronic conduction with which we shall be concerned. Some materials show conductivities which approach those of certain metals, and yet their conduction process is found to be like that of other semiconductors. Insulators may, under certain conditions, show conduction behavior which is characteristic of semiconduction. Another criterion commonly associated with semiconduction is a negative temperature coefficient of resistance.

Semiconductors depend in many cases on crystal imperfections for their unique properties. These may be foreign atoms incorporated into the crystal lattice, small deviations from stoichiometry, or lattice defects. As might be expected from the wide range in conductivities encountered, a large number of materials can be considered as semiconductors. Among the most investigated, and best understood, of these, are germanium and silicon among the elements, and indium antimonide, zinc oxide, and cadmium sulphide among the compounds.

Semiconductors are of practical importance in a number of connections. Their most direct uses, of course, take advantage of their unique electrical behavior, as in transistors, crystal rectifiers, and thermisters. Closely related to these are the applications which combine electrical and optical effects, as in luminescent materials and photocon-ductors. Furthermore, semiconductors are used in many other ways, in which any connection between their semiconducting behavior and the particular application is much more subtle. An example of this, of particular interest to is that of the oxide catalysts.

ELECTRONS AND HOLES

In many semiconductors it is of great importance to recognize two kinds of carriers of electrical current: electrons and holes. While the latter, in the final analysis, represent motion of electrons also, the separation of the two basic conduction processes is clear. The concept involved will be illustrated in terms of chemical bonds, by reference to the elements of Group IV although they are quite general for solids.

The covalently bonded carbon atoms, in the diamond modification, are shown in Fig. Since each carbon contributes four valence electrons, and it is tetrahedrally bonded to four neighboring carbons, all of the electrons are used up in forming the covalent bonds. In this situation no net flow of electrons through the solid is possible, and the material is an insulator.

If an extra electron is added to the structure, however, no empty bonds are available, and the electron is free to wander through the solid. It will move through the crystal in the opposite direction from an applied electric field, and can thus contribute to the electrical conductivity. This situation is shown in Fig. Electrons which are not bound in the valence bonds, and thus free to move in this way, are called conduction electrons. If conduction electrons can be produced in some manner in sufficient quantity, the material Is no longer an insulator, but shows appreciable electrical conductivity.

There is n second way in which the total number of electrons fails to match the number of available bonding sites, i.e., when there are too few electrons. There is then only one electron in some of the bonds, as shown in Fig. This missing bonding electron is called a "hole". It, like the conduction electron, is free to wander through the crystal. As shown in Fig., an electron in a bond adjacent to the one-electron bond where the "hole" is localized, can jump into the empty position, leaving a vacancy behind as it goes. As this process is repeated, the net effect is for the hole to move through the crystal under the influence of an electric field; it can be seen that the hole will move in the opposite! direction from the conduction electron, since the motion of the hole is opposite to that of the valence electrons.

IMPURITY SEMICONDUCTORS

Using germanium, which crystallizes in the diamond lattice, as an example, the effect of adding certain foreign atoms in substitutional positions in the crystal may be seen easily. If a germanium atom is replaced by an atom of an element from Group V, such as arsenic there are five valence electrons from the arsenic to be disposed of. Four of these are shared with the four adjacent germanium atoms, to form covalent bonds similar to those existing between adjacent germanium atoms. The fifth electron will not be held in any chemical bond, as there are no empty sites available. It will be attracted weakly by the arsenic, however, by coulombic forces, as its removal to large distances leaves the arsenic with a net positive charge. When the electron is at large distances the only available energy state is in the conduction band. The energy required to remove the electron is called the impurity ionization energy, and the term donor derives from the fact that the arsenic can "donate" a conduction electron to the lattice.

The replacement of a germanium atom by an element of Group III, indium for example, leads to a deficiency in valence electrons. Referring to the schematic picture of Fig., the three electrons contributed by the indium form covalent bonds with three of the four adjacent germanium atoms, but the fourth bond remains a one-electron bond, i.e., a hole is formed. Just as the electron was weakly held to the arsenic by coulombic forces, the hole is attracted to the indium. If it moves away, the fourth covalent bond to the indium is completed, and the indium is left with a net negative charge. Group III elements are examples of acceptors, so called because they can "accept" electrons, thereby Introducing holes into the valence band.

The examples chosen to illustrate donors and acceptors are particularly simple, but they are not the only kind of donor and acceptor. They both belong to a general class which run be called "impurity centers", as they arise from the introduction of a chemical impurity into the lattice, and the semiconductors arising from this kind of imperfection can be called "impurity semiconductors". Certain elements from other groups of the periodic table may also act as donors and acceptors in substitutional positions in germanium and silicon.

Certain impurities which enter the lattice in interstitial positions, may also be donors in semiconductors. Lithium in silicon and germanium is an example. The neutral lithium atom has a single valence electron, and is known to occupy (normally) an interstitial site. The odd electron is easily removed, leaving an interstitial positive lithium ion. The electrical consequences of an interstitial donor, like lithium, are entirely similar to those of substitutional donors like arsenic. One might ask whether interstitial acceptors also exist. No such case has been established, and possibly this is due to the difficulty of fitting a large negative ion into an interstitial site.

The same general scheme holds for donors and acceptors in compound semiconductors. In Group III –Group V compounds, such as GaAs, one expects, and finds, that elements Of Group VI, substitution ally replacing arsenic, act as donors, while elements of Group II, if they occupy gallium sites, act as acceptors. Similar considerations hold in other compound semiconductors, such as the II-VI compounds.

ENERGY LEVELS AND ACCEPTORS

A way of introducing donors and acceptors into semiconductors arises from nonstoichiometry in compounds. Several possible ways this might happen can be foreseen. The nonstoichiometry can arise either by virtue of vacant lattice sites for one component of the compound, or because of an excess of one component located in interstitial sites. Anion or cation excesses or deficiencies might be involved, and we might be concerned with either donors or acceptors.

To illustrate how nonstoichiometry leads to such effects, we consider only a single example here. A donor center can result from the trapping of one or more electrons in an anion vacancy. The classic examples of centers of this type are the F-rmters in alkali halides, although these materials are not usually considered semiconductors. The same kind of center is believed to result from nonstoichiometry in CdS. t ihow in Fig. 3 a crystal of CdS. We show in Fig a crystal of CdS, in which a few anion lattice sites are vacant, corresponding to a stoichiometric excess of cadmium. In order to maintain charge neutrality in the crystal, two electrons must be supplied for every ion removed. In the vicinity of the vacancy, there is a net positive charge, and there will be, a strong tendency for the extra electrons to be held to this centre, and this combination, the electrons trapped in the anion vacancy, is the donor centre. If, by some means, any of these trapped electrons can be released, they enter the conduction band of the crystal and increase the electrical conductivity.

In the case of arsenic in germanium, it is apparent that the fifth electron lies in a higher energy state than the normal valence electrons, so that the localized extra level associated with the arsenic lies above the top of the filled band. At the same time, since there is some binding energy for an electron in this state to remain on the arsenic, the level lies below the lowest "free" electron state in the conduction band. The extra state must therefore lie in the forbidden y gap, as shown in Fig. The energy required to remove this electron may be estimated by noting the similarity to the removal of an electron from a hydrogen atom. The coulombic attraction between the arsenic and the electron, as compared with the hydrogen atom, is reduced by the dielectric constant of the medium, since the electron orbit in the solid encompasses several atomic distances. The reduction in ionization energy depends on the square of the dielectric constant, which is 15.8 for germanium. The ionization energy for the free hydrogen atom is 13.6 eV, so one expects the ionization energy for arsenic in germanium to be reduced by a factor $(15.8)^2$, thus $13.6/(15.8)^2= 0.05$ eV.

A further reduction is expected because the effective mass for electrons should be used, rather than the actual electronic mass, in computing the energy. This reduction leads to good agreement with the experimental values, which lie near 0.01 eV. This, then, is the energy difference between the bottom of the conduction band and the localized energy level at an arsenic. Similar considerations show that an acceptor like boron provides levels just above-the top of the filled band, as shown in Fig. Centers like these: are often called "hydrogen-like".

At room temperature, the thermal excitation energy of the electrons is sufficient to ionize almost completely arsenic centers in germanium, so there is an increased concentration of electrons in the conduction band nearly equal to the arsenic concentration, and these give rise to an increase in the electrical conductivity. Such behavior is called "extrinsic", as it depends on the concentration of imperfections in the lattice. The case of boron in germanium provides #n example of an extrinsic semiconductor where an excess of holes has been introduced. At room temperature the boron levels are nearly all ionized, that is to say, the holes have been removed from them and have entered the valence band, leaving an electron trapped on each acceptor center.

Not all donors and acceptors in germanium have as small ionization energies as do boron and arsenic, and larger ionization energies are encountered in other materials also. When both acceptors and donors are present in material – and for practical reasons this will almost always occur to some degree – there is a "compensation" effect. The difference between donor and acceptor concentration will determine the carrier concentration. Thus, in Fig. with five arsenic and two boron atoms present, the boron levels are filled by two of the available electrons from the arsenic and only three conduction electrons are supplied.

SEMICONDUCTORS

The periodic law of elements discovered by Mendelyeev had a number of important scientific and industrial results, one of them being the discovery of germanium. Germanium is the semiconductor used in most transistors available at present.

But what are semiconductors? They include almost all minerals, many chemical elements, a great variety of chemical compounds, alloys of metals, and a number of organic compounds. Like metals, they conduct electricity but they do it less effectively. In metals all electrons are free and in insulators they are fixed. In semiconductors electrons are fixed, too, but the connection is so weak that the heat motion of the atoms of a body easily pulls them away and sets them free.

It is not difficult to understand that the term "semiconductor" has been used because the material in question really occupies a place between the conductors of the electric current and the non-conductors, that is insulators. The term shows that they conduct electricity less readily than conductors but much better than insulators.

Minerals and crystals appear to possess some unexpected properties. For instance, it is well known that their conductivity increases with heating and falls with cooling.

As a semiconductor is heated, free electrons in it increase in number, hence, its conductivity increases as well now-ever, heat is by no means the only phenomenon influencing semiconductors. They are sensitive to light, too. Take germanium as an example. Its electrical properties may greatly change when it is exposed to light. With the help of a ray light directed at a semiconductor, we can start or. stop various machines, effect remote control, and perform lots of other useful things. Just as they are influenced by falling light, semiconductors are also influenced by all radiation. Generally speaking, they are so sensitive that a heated object can be detected by its radiation.

As previously mentioned, such dependence of conductivity on heat and light has opened up great possibilities for various uses of semiconductors. The semiconductor devices are applied for transmission of signals, for automatic control of a variety of processes, for switching on engines, for the reproduction of sound, protection of high-voltage transmission lines, speeding up of some chemical reactions, and so on. On the one hand they may be used to transform light and heat energy directly into electric energy without any complex mechanism with moving parts, and on the other hand, they are capable of generating heat or cold from electricity.

Soviet engineers and scientists turned their attention to semiconductors more than thirty years ago. They saw in them a means of solving an old engineering problem, namely, that of direct conversion of heat into electricity without boilers or machines. Semiconductor thermocouples created in the USSR convert heat directly into electricity just as a complex system consisting of a steam boiler, a steam engine and a generator does it.

SUPERCONDUCTIVITY

According to the prominent scientist in this country V.L. Ginzburg the latest world achievements in the field of superconductivity mean a revolution in technology and industry. Recent spectacular breakthroughs in superconductors may be compared with the physics discoveries that led to electronics and nuclear power. They are likely to bring the mankind to the threshold of a new technological age. Prestige, economic and military benefits could well come to the nation that first will master this new field of physics. Superconductors were once thought to be physically impossible. But in 1911 superconductivity was discovered by a Dutch physicist K. Onnes, who was awarded the Nobel Prize in 1913 for his low-temperature research. He found the electrical resistivity of a mercury wire to disappear suddenly when cooled below a temperature of 4 Kelvin (-269 °C). Absolute zero is known to be O K. This discovery was a completely unexpected phenomenon. He also discovered that a superconducting material can be returned to the normal state either by passing a sufficiently large current through it or by applying a sufficiently strong magnetic field to it. But at that time there was no theory to explain this.

For almost 50 years after K. Onnes' discovery theorists were unable to develop a fundamental theory of superconductivity. In 1950 physicists Landau and Ginzburg made a great contribution to the development of superconductivity theory. They introduced a model which proved to be useful in understanding electromagnetic properties of superconductors. Finally, in 1957 a satisfactory theory was presented by American physicists, which won for them in 1972 the Nobel Prize in physics. Research in superconductors became especially active since a discovery made in 1986 by IBM scientists in Zurich. They found a metallic ceramic compound to become a superconductor at a temperature well above the previously achieved record of 23 K.

It was difficult to believe it. However, in 1987 American physicist Paul Chu informed about a much more sensational discovery: he and his colleagues produced superconductivity at an unbelievable before temperature 98 K in a special ceramic material. At once in all leading laboratories throughout the world superconductors of critical temperature 100 K and higher (that is, above the boiling temperature of liquid nitrogen) were obtained. Thus, potential technical uses of high temperature superconductivity seemed to be possible and practical. Scientists have found a ceramic material that works at room temperature. But getting superconductors from the laboratory into production will be no easy task. While the new superconductors are easily made, their quality is often uneven. Some tend to break when produced, others lose their superconductivity within minutes or hours. All are extremely difficult to fabricate into wires. Moreover, scientists lack a full understanding of [low ceramics become superconductors. This fact makes developing new substances largely a random process. This is likely to continue until theorists give a fuller explanation of how superconductivity is produced in new materials.

ELECTROMOTIVE FORCE AND RESISTANCE

As was previously stated, there is always a disorderly movement of free electrons within all substances, especially metals.

Let us assume that there is a movement of electrons through the wire, say, from point A to point B. What does it mean? It means that there is an excess of electrons at point A. Unless there were a flow of electric current between A and B in any direction, it would mean that both the former and the latter were at the same potential. Of course, the greater the potential difference, the greater is the electron flow.

The electromotive force (e.m.f.) is the very force that moves the electrons from one point in an electric circuit towards another. In case this e.m.f. is direct, the current is direct. On the other hand, were the electromotive force alternating, the current would be alternating, too. The c.in.f. is measurable and it is the volt that is the unit used for measuring it.

One need not explain to the reader that a current is unable to flow in a circuit consisting of metallic wires alone. A source of an e.m.f. should be provided as well. The source under consideration may be a cell or a battery, n generator, a thermocouple or a photocell, etc.

In addition to the electromotive force and the potential difference reference should be made here to another important factor that greatly influences electrical flow, namely, resistance. So, to resistance shall we turn our attention now. The student probably remembers that all substances offer a certain amount of opposition, that is to say resistance, to the passage of current. This resistance may be high or low depending on the type of circuit and the material employed. Take glass and rubber as an example. They offer a very high resistance and, hence, they are considered as good insulators. Nevertheless, one must not forget that all substances do allow the passage of some current provided the potential difference is high enough.

Imagine two oppositely charged balls suspended far apart in the air. In spite of our having a difference of potential, no current flows. How can we explain this strange behaviour? The simple reason is that the air between the balls offers too great a resistance to current flow. However, the electrons could certainly flow from the negatively charged ball towards the positively charged one provided we connected them by a metal wire. As a matter of fact, it is not necessary at all to connect both balls in the manner described in order to obtain a similar result. All that we have to do is to increase the charges. If the potential difference becomes great enough, the electrons will jump through the air forming an electric spark.

One should mention in this connection that certain factors can greatly influence the resistance of an electric circuit. Among them we find the size of the wire, its length, and type. In short, the thinner or longer the wire, the greater is the resistance offered. Besides, could we use a silver wire, it would offer less resistance than an iron one.

MAGNETIC EFFECT OF AN ELECTRIC CURRENT

The invention of the voltaic cell in 1800 gave electrical experimenters a source of a constant flow of current. Seven years later the Danish scientist and experimenter, Oersted, decided to establish the relation between a flow of current and a magnetic needle. It took him at least 13 years - more to find out that a compass needle is deflected when brought near a wire through which the electric current flows. At last, during a lecture he adjusted, by chance, the wire parallel to the needle. Then, both he and his class saw that when the current was turned on, the needle deflected almost at right angles towards the conductor. As soon as the direction of the current was reversed, the direction the needle pointed in was reversed too.

As seen the north end of the needle moves away from us when the current flows from left to right. Oersted also pointed out that provided the wire were adjusted below the needle, the deflection was reversed.

The above-mentioned phenomenon highly interested Ampere who repeated the experiment and added a number of valuable observations and statements. He began his research under the influence of Oersted's discovery and carried it on throughout the rest of his life.

Everyone knows the rule thanks to which we can always find the direction of the magnetic effect of the current. It is known as Ampere's rule. Ampere established and proved that magnetic effects could be produced without any magnets by means of electricity alone. He turned his attention to the behaviour of the electric current in a single straight conductor and in a conductor that is formed Into a coil, i.e. a solenoid.

When a wire conducting a current is formed into a coil of several turns, the amount of magnetism is greatly increased.

It is not difficult to understand that the greater the number of turns of wire, the greater is the m.m.f. (that is I he magnetomotive force) produced within the coil by any constant amount of current flowing through it. In addition, when doubling the current, we double the magnetism generated in the coil.

A solenoid has two poles which attract and repel the |poles of other magnets. While suspended, it takes up a north and a south direction exactly like the compass needle.

A core of iron becomes strongly magnetized if placed within the solenoid while the current is flowing.

When winding a coil of wire on an iron core, we obtain an electromagnet. That the electromagnet is a controllable and reliable magnet is perhaps known to everyone. It is, so to say, a temporary magnet provided by electricity. Its behaviour is very simple. The device is lifeless unless an electric current flows through the coil. However, the device comes to life provided the current flows. The iron core will act as a magnet as long as the current continues to pass along the winding.

THE DISCOVERY OF ELECTRO-MAGNETIC INDUCTION

It is at this important juncture in the history of electrical research that we see the first, shy attempts to make this force of Nature do some work. Now we are concerned with the development of electricity for the transmission of energy.

One day in 1819 a Danish physicist, Hans Christian Oersted, was lecturing at the University of Kiel, which was then a Danish town. Demonstrating a galvanic battery, he held up a wire leading from it when it suddenly slipped out of his hand and fell on the table across a marine's compass that happened to be there. As he picked up the wire again he noticed to his astonishment that the needle of the compass no longer pointed north, but had swung completely out of position. He switched the current off, and the needle pointed north again.

For a few months he thought over this incident, and eventually wrote a short report on it. No one could have been more surprised than Oersted at the extraordinary impact which his discovery made on physicists all over Europe and America. At last the longsought connection between electricity and magnetism had been found! Yet neither Oersted nor his colleagues could forsee the importance of this phenomenon, for it is the connection between electricity and magnetism on which the entire practical use of electricity in our time is foundedy

What was it that Oersted had discovered? Nothing more than that an electrically charged conductor, such as the wire leading from a battery, is the centre of a magnetic 'field', and this has the effect of turning a magnetic needle at a right angle with the direction in which the current is flowing; not quite at a right angle, though, because the magnetism of the earth also influences the needle. Now the physicists had a reliable means of measuring the strength of a weak electric current flowing through a conductor; the galvanoscope, or galvanometer, is such a simple instrument consisting of a few wire loops and a magnetic needle whose deflection indicates the strength of the current.

Prompted by the research work of Andre-Marie Ampere, the great French physicist whose name has become a household word as the unit of the electric current, the Englishman Sturgeon experimented with ordinary, non-magnetized iron. He found that any piece of soft iron could be turned into a temporary magnet by putting it in the centre of a coil of insulated wire and making an electric current flow through the coil. As soon and as long as the current was turned on the iron was magnetic, but it ceased to be a magnet when there was no more current. Sturgeon built the first large electro-magnet, and. with this achievement there began the development of the electrical telegraph and later the telephone.

But there was yet another, and perhaps even more important, development which began with the electro-magnet. Michael Faraday repeated the experiments of Oersted, Sturgeon, and Ampere. His brilliant mind conceived this idea: if electricity could produce magnetism, perhaps magnetism could produce electricity!

But how? For a long time he searched in vain for an answer. Every time he went for a walk in one of London's parks he carried a little coil and a piece of iron in his pocket, taking them out now and then[1] to look at them. It was on such a walk that he found the solution. Suddenly, one day in 1830, in the midst of Green Park (so the story goes), he knew it: the way to produce electricity by magnetism was – by motion. He hurried to his laboratory and put his theory to the test. It was correct.

A stationary magnet does not produce electricity. But when a magnet is pushed into a wire coil current begins to flow in the coil; when the magnet is pulled out again, the current flows in the opposite direction. This phenomenon, confirms the basic fact that the electric current cannot be produced out of nothing–some work must be done to produce it. Electricity is only a form of energy; it is not a 'prime mover' in itself.

What Faraday had discovered was the technique of electro-magnetic induction, on which the whole edifice of electrical engineering rests. He soon found that there were various ways of transforming motion into electric current. Instead of moving the magnet in and out of the wire coil you can move the coil towards and away from the magnet; or you can generate electricity by changing the strength of stationary magnet; or you can produce a current in one of two coils by moving them towards and away from each other while a current is flowing in the second.

Faraday then substituted a magnet for the second coil and observed the same effect. Using two coils wound on separate sections of a closed iron ring, with one coil connected to a galvanometer and the other to a battery, he noticed that when the circuit of the second coil was closed the galvanometer needle pointed first in one direction and then returned to its zero position. When he interrupted the battery circuit, the galvanometer jerked into the opposite direction. Eventually, he made a 12-inch-wide copper disc which he rotated between the poles of a strong horse-shoe magnet; the electric current which was generated in the copper disc could be obtained from springs or wire brushes touching the edge and axis of the disc.

Thus Faraday demonstrated quite a number of ways in which motion could be translated into electricity. His fellow-scientists at the Royal Institution and in other countries were amazed and impressed – yet neither he nor they proceeded to make practical use of his discoveries, and nearly forty years went by before the first electric generator, or dynamo, was built.

Meanwhile, fundamental research into the manifold problems of electricity continued. In America, Joseph Henry, professor of mathematics and natural science, also starting from Oersted's and Sturgeon's observations, used the action of the electric current upon a magnet to build the first primitive electric motor in 1829. At about the same time, Georg Simon Ohm, a German school-teacher found the important law of electric resistance: that the amount of current in a wire circuit decreases with the length of the wire, which acts as resistance. Ohm's excellent research work remained almost unnoticed during his lifetime, and he died before his name was accepted as that of the unit of electrical resistance.

GENERATORS

The dynamo invented by Faraday in 1831 is certainly a primitive apparatus compared with the powerful, highly efficient generators and alternators that are in use today» Nevertheless, these machines operate on the same principle as the one invented by the great English scientist. When asked what use his new invention had, Faraday asked in his turn: "What is the use of anew-born child?" As a matter of fact, "the new-born child" soon became an irreplaceable device we cannot do without.

Although used to operate certain devices requiring small currents for their operation, batteries and cells are unlikely to supply light, heat and power on a large scale. Indeed, we need electricity to light up millions of lamps, to run trains, to lift things, and to drive the machines. Batteries could not supply electricity enough to do all this work.

That dynamo-electric machines are used for this purpose is a well-known fact. These are the machines by means of which mechanical energy is turned directly into electrical energy with a loss of only a few per cent. It is calculated that they produce more than 99.99 per cent of all the world's electric power.

There are two types of dynamos, namely, the generator and the alternator. The former supplies d.c. which is similar to the current from a battery and the latter, as its name implies provides a.c.

To generate electricity both of them must be continuously provided with energy from some outside source of mechanical energy such as steam engines, steam turbines or water turbines, for example.

Both generators and alternators consist of the following principal parts: an armature and an electromagnet. The electromagnet of a d.c. generator is usually called a stator for it is in a static condition while the armature (the rotor) is rotating. Fig. 7 shows the principles the construction of an elementary d.c. generator is based upon. We see the armature, the electromagnet, the shunt winding, the commutator and the load. Alternators may be divided into two types: 1. alternators that have a stationary armature and a rotating electromagnet; 2. alternators whose armature serves as a rotor but this is seldom done. In order to get a strong e.m.f., the rotors in large machines rotate at a speed of thousands of revolutions per minute (r.p.m.). The faster they rotate, the greater the output voltage the machine will produce.

In order to produce electricity under the most economical conditions, the generators must be as large as possible. In addition to it, they should be kept as fully loaded as possible all the time. It is interesting to note here that the biggest generators ever installed at any hydroelectric station in the world are those installed in the USSR. As you are likely to remember the Bratskaya hydroelectric station is equipped with 225,000 kilowatt (kW) generators. Soviet scientists constructed more powerful generators which are installed at the Krasnoyarskaya station. The Konakovskaya, the Zaporozhskaya and the Uglegorskaya steam power-stations have large rated capacity. Our industry produces even greater power installations of 1,200 MW for the steam power plants which play such an important par, in the electrification plan of the USSR.

POWER TRANSMISSION

They say that about a hundred years ago, power was never carried far away from its source. Later on, the range of transmission was expanded to a few miles. And now, in a comparatively short period of time, electrical engineering has achieved so much that it is quite possible, at will, to convert mechanical energy into electrical energy and transmit the latter over hundreds of kilometres and more in any direction required. Then in a suitable locality the electric energy can be reconverted into mechanical energy whenever it is desirable. It is not difficult to understand that the above process has been made possible owing to generators, transformers and motors as well as to other necessary electrical equipment. In this connection one cannot but mention the growth of electric power generation in this country. The longest transmission line in pre-revolutionary Russia was that connecting the Klasson power-station with Moscow. It is said to have been but 70 km long, while the pre sent Volgograd–Moscow high-tension transmission line is over 1000 kilometres long. (The reader is asked to note that the English terms "high-tension" and "high-voltage" are interchangeable.) Generally speaking, the length of high-tension transmission lines in the Soviet Union is so great that they could circle the globe six times, if not more.

It goes without saying that as soon as the electric energy is produced at the power-station, it is to be transmitted over wires to the substation and then to the consumer. However, the longer the wire, the greater is its resistance to current flow. On the other hand, the higher the offered resistance, the greater are the heating losses in electric wires. .One can reduce these undesirable losses in' two ways, namely, one can reduce either the resistance or the current. It is easy for us to see how we can reduce resistance: it is necessary to make use of a better conducting material and as thick wires as possible. However, such wires are calculated to require too much material and, hence, they will be too expensive. Can the current be reduced? Yes, it is quite possible to reduce the current in the transmission system by employing transformers. In effect, the waste of useful energy has been greatly decreased due to high-voltage lines. It is well known that high voltage means low current, low current in its turn results in reduced heating losses in electrical wires. It is dangerous, however, to use power at very high voltages for anything but transmission and distribution. For that reason, the voltage is always reduced again before the power is made use of.

Lasers. Soviet scientists are successfully developing quantum generators, called lasers, for emitting light amplitude radio waves. Theoretical calculations have shown that lasers are very likely to transform the energy of light radio waves into electrical energy with an efficiency amounting to about 100 per cent. It means that electrical power might be transmitted over considerable distances with negligible losses and what is very important without the use of transmission lines.

TRANSMISSION LINE

Although presently operating at 230 kv, the transmission line is designed and fully insulated for operation at 345 kv, using an additional conductor per phase. Provision has been made and hardware provided for the intsallation of this second-phase conductor; it will be strung prior to conversion to 345 kv, which is anticipated in the course of the next 2 or 3 years.

Apart from the extra-high voltage aspect, however, there are a number of features of design and construction which are worthy of mention. The first concern the use of aerial photography for acquisition of the right-of-way** as well as spacing and location of the line structures.

Initial reconnaissance of the route was made by helicopter, and aerial photography was used to make final selection; then photographs of this route were obtained to a scale of 200 feet to the inch. On these photographs were superimposed all property lines, road boundaries, the boundaries of the proposed right-of-way and legal descriptions of the property traversed. Final land survey for registration purposes followed at a later date. The right-of-way acquired is 450 feet in width, to provide for two additional similar circuits at some future date.

Concurrent with the selection of a suitable route was the design and fabrication of the towers. The conductor selected was 795,000 circular-mil 26/7 steel-reinforced aluminum cable, using a twin bundle per phase at 18-inch centers; phase spacing was 35 feet. The conductor was suspended from 21 unit insulator strings***, with specially designed grading rings attached at the lower ends. The maximum design tension in the conductor was one-half its ultimate strength. The maximum design loading was 1/2 inch of radial ice, plus 4 pounds per square foot wind pressure at zero degrees Fahrenheit. As the lightning incidence in this area is very low, ground wires were installed for only 1/2 mile at the line terminals.

After considerable study as to the type of tower to be employed on this line, the portal type was finally selected. Fig. 26 shows a tangent tower. This type of tower offers a number of distinct advantages for this application. By the use of two masts, instead of the quadruped construction normally used, the weight of redundant steel is considerably reduced, particularly in the tower head. At extra-high voltages, this reduction becomes increasingly important. Another advantage is that the two masts offer very little obstruction to the use of agricultural equipment around the tower. This was a factor, as 59 of the 64 miles of line pass through highly cultivated farmland. The third advantage lay in the ease of erection for this type of tower.

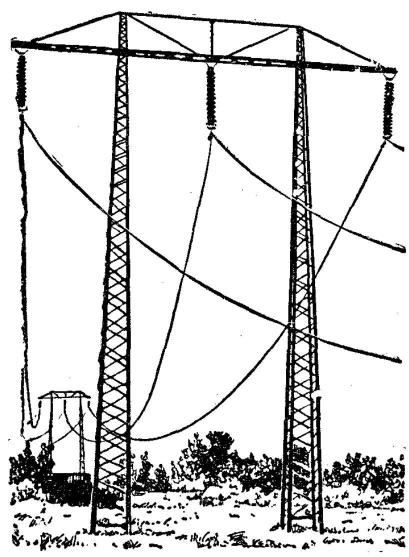

Fig. 26.

The specification called for a standard mast to be designed to meet the requirements for tangent, angle, and dead-end towers. On angle towers, the transverse load was to be taken by internal guys, and similarly, on deadend towers the conductor tension was to be taken by guys. Thus, the mast designed for the tangent tower could be used for all towers, and only separate crossarms need be detailed. This effected a considerable saving in detailing cost and simplified erection.

The maximum line span was 1,222 feet and the minimum 514 feet. The average span was 995 feet.

Every suspension tower was to be capable of withstanding a longitudinal load due to both conductors

of one phase being broken.
In order to reduce the dynamic load on the tower Masts when a conductor breaks, it was decided that the crossarm should be designed to fail at 60 per cent of the actual broken-wire load, that is, a safety factor of one applied to the broken-wire load as described above. Upon failure the crossarm would swing into the line, thus reducing both the dynamic and the static load on the tower.

A total of 340 towers were constructed on this line over a period of 8 months. The great majority of towers were erected by completely assembling the masts on the ground and then erecting them by means of a mobile crane. A 2-masted tower took approximately one day to assemble on the ground and 2 hours to erect.
Twenty-three months after commencement the line was completed; it was energized at 280 kv on November 30, 1952.

TRANSFORMERS

The transformer is a device for changing the electric current from one voltage to another. As a matter of fact, it is used for increasing or decreasing voltage. A simple transformer is a kind of induction coil. It is well known that in its usual form it has no moving parts. On the whole, it requires very little maintenance provided it is not misused and is not damaged by lightning.

We may say that the principal parts of a transformer are two windings, that is coils, and an iron core. They call the coil which is supplied with current the "primary winding", or just "primary", for short. The winding from which they take the current is referred to as the "secondary winding" or "secondary", for short. It is not new to you that the former is connected to the source of supply, the latter being connected to the load.

When the number of turns of wire on the secondary is the same as the number on the primary, the secondary voltage is the same as the primary, and we get what is called a "one-to-one" transformer. In case, however, the number of turns on the secondary winding is greater than those on the primary, the output voltage is larger than the input voltage and the transformer is called a step-up transformer. On the other hand, the secondary turns being fewer in number than the primary, the transformer is known as a step-down transformer.

The transformer operates equally well to increase the voltage and to reduce it. By the way, the above process needs a negligible quantity of power. It is important to point out that the device under consideration will not work on d.c. but it is rather often employed in direct-current circuits.

Fig. 8 shows how transformers are used in stepping up the voltages for distribution or transmission over long distances and then in stepping these voltages down. In this figure, one may see three large step-up transformers which are used to increase the potential to 275,000 volts for transmission over long-distance transmission lines At the consumers end of the line, in some distant locality three step-down transformers are made use of to reduce hat valued (i.e., 275,000 volts) to 2,300 volts. Local transformers, in their turn, are expected to decrease the 2,300 volts to lower voltages, suitable for use with small-motors and lamps. One could have some other transformers in the system that reduce the voltage even further. All radio sets and all television sets are known to use two or more kinds of transformers. These are familiar examples showing that electronic equipment cannot do without transformers. The facts you have been given above illustrate the wide use of transformers and their great importance

Another alternating-current system of transmission and distribution is shown in Fig. 9. You are asked to follow the whole process, that is, to describe it from beginning to end.

TRANSFORMERS

Faraday's experiments of August 29, 1831, gave us the principle of the electric transformer, without which the later discoveries of that fateful year could have little real practical application. For to convey electric current over long distances, say to supply a town, or feed an electric railway, it is necessary to generate it at a very high voltage, or force. By means of transformers based on Faraday's Induction coil discovery, it is simple for a current from the grid or direct from a power-station of say 132.000 volts to be stepped down for the electric train to 600 volts and for household use to 240 volts. Smaller transformers in individual prices of electrical equipment, say a shaver or radio, may step the current down still further for special purposes. Similarly, currents may be stepped up in voltage, if required, by the same device. The procedure is quite simple. The current is fed into the transformer across the primary, of input coil, which corresponds to Faraday's right-hand coil on his induction ring. The resultant induced current is taken from the secondary, of output coil, which corresponds to Faraday's left-hand coil. If this secondary coil has more windings of wire than the primary coil, the voltage will be stepped down.

So the two related discoveries of 1831 provided not only the means of making electricity easily and cheaply, on as large a scale as required, without any cumbersome batteries, but also the way of using it in a safe and practical way.

PRINCIPLES OF OPERATION

Theory of Transformer Action.– A transformer may be defined as a piece of apparatus* without continuously moving parts, which by electromagnetic induction transforms alternating voltage and current in one winding into alternating voltage and current in one or more other windings, usually at different values of voltage and current. It consists essentially of an iron core on which are wound the primary and secondary windings.

When an alternating voltage is applied to the terminals of the primary winding, the secondary being open-circuited, the apparatus behaves like a choking coil. An alternating magnetic flux is set up and this induces a back e.m.f. in the primary winding. Neglecting losses, this back e.m.f. exactly neutralizes the applied e.m.f.,

each turn of the winding providing its own proper proportion of the total volt-age. The alternating magnetic flux also induces an e.m.f. in the turns of the secondary winding, the volts per turn being the same for both windings.
In actual practice, the induced e.m.f. in the primary windings is very slightly less than the applied voltage, on account of voltage drops in the circuit. Similarly, the induced e.m.f. in the secondary windings is very slightly greater than the secondary terminal voltage, when the transformer is delivering a load current, for the same reason. The voltage ratio is therefore slightly greater than the turns ratio.

* as a piece of apparatus как прибор; piece употребляется в качестве счётного слова для указания на отдельный предмет. Обычно в подобном сочетании на русский язык не переводится.

EQUIVALENT CIRCUITS

An actual transformer may be represented, for purposes of explanation, as consisting of an ideally perfect transformer, having no losses or magnetizing current, together with various additions to allow for these effects.

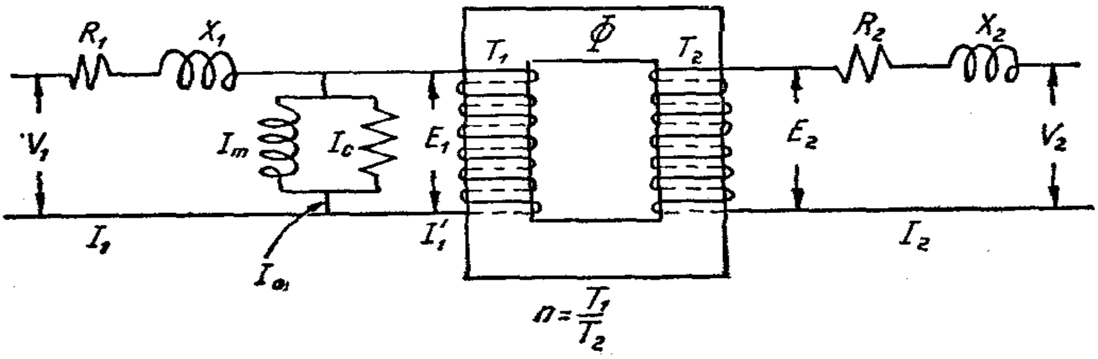

Fig. 13. Equivalent Circuits of a Transformer

Fig. 13. represents such an ideal transformer having a resistance, R_1, and a reactance X_1, in series with its primary winding, and a resistance, R_2, and a reactance, X_2, in series with its secondary winding. The no-load current has both an active and a reactive component The latter is the magnetizing current of the iron core, I_m, and is represented in the diagram by the current flowing through an additional reactance, while the active component, I_c, supplying the iron losses in the core, is represented by the current flowing through an additional resistance. The vector resultant of I_m and I_c is I_0, which is the total no-load current of the transformer. The secondary current is I_2, and the component of the primary current that neutralizes I_2 is I'_1 The total primary current, I_1, is the vector sum of this component, I'_1, and the no-load current, I_2. The turns in the primary and secondary windings are T_1 and T_2 respectively, and are so related that

$$\frac{I_2}{I_1^{'}} = \frac{T_1}{T_2} = n = turns\ ratio$$

The flux Φ is the useful flux linking both primary and secondary windings. The induced secondary e.m.f. is E_2, this being slightly greater than the secondary terminal voltage, V_2, since the secondary resistance, R_2, and the secondary reactance, X_2, cause voltage drops of I_2R_2 and I_2X_2 in phase and in quadrature with the current, I_2, respectively. The back induced e.m.f., E_1, is related to E_2 by the formula

$$\frac{E_1}{E_2} = \frac{T_1}{T_2} = n = turns\ \ ratio.$$

The primary applied voltage, V_1, is again slightly larger than E_1, on account of the voltage drops caused by the primary resistance, R_1, and the primary reactance, X_1. These again bring about voltage drops of I_1R_1 and I_1X_1 in phase and in quadrature with the primary current, I_1, as before.

AUXILIARY EQUIPMENT

Methods of Cooling

Various methods of cooling transformers are adopted in practice, depending upon the size and the local conditions. Very small transformers are cooled naturally by the atmosphere, no special cooling arrangements being necessary. Slightly larger transformers are oil-immersed, being enclosed in a tank for this puprose. The object of the oil is twofold. As an insulator, it is better than air, and it also keeps down the maximum temperature rise by setting up convection currents which tend to equalize the temperature. These convection currents carry the heat away to the walls and lid of the tank, whence it is dissipated into the atmosphere. Small tanks are made with a plain exterior, sufficient cooling surface being obtained in this manner. Rather larger tanks are made with a corrugated exterior, or are provided with fins, to increase the cooling surface. A more popular arrangement, however, is to obtain the desired increase in cooling surface by means of a number of tubes running from top to bottom on the outside of the tank. The oil immediately in contact with the transformer in the tank is heated by the transformer, and consequently rises. Convection currents cause the oil to flow outwards at the top of the tank and so it enters the tubes at the top. It is now cooled in the tubes, sinks, and re-enters the tank at the bottom. It is now heated again by the transformer, and the cycle of operations is repeated.

The larger the tank, the greater is the number of tubes required. These are now arranged in rows, one behind the other, but very little advantage is gained by adding more tubes when they are already three deep. A fourth row of tubes is so shut in by the tubes on the outside that very little additional cooling surface is obtained. When this stage is reached, the simple tubular design is abandoned, and external radiators are substituted for the tubes.

With this type of cooling the tank surface itself now becomes plain again. The external radiators consist of a long horizontal chamber at the top, and another at the bottom, these being joined by numbers of radiator tubes.

Other transformers designed for use with an external oil cooler have no radiators fitted to the transformer tank itself, practically the whole of the heat dissipation taking place in the oil cooler.

Water-cooling is also employed. A number of tubes are arranged in a helical coil inside the top of the transformer tank, but underneath the oil level. A stream of cold

water is then passed through this cooling coil. Since the presence of even a minute percentage of water in the oil reduces its insulating properties to an enormous degree, it is extremely important that no water should escape through any leak, should one occur.* In order to prevent this, the tank is made oil-tight and the oil is put under pressure. If a leak should develop, oil will leak into the tubes (which does not much matter) instead of the water leaking into the oil.
In confined spaces, and where a supply of water is not available, air-blast cooling may be adopted. The tank is now dispensed with**, and a blast of cold air is forced over the transformer windings. Cooling by this means is usually confined to transformers operating on the lower voltages.

* it is extremely important that no water should escape through any leak, should one occur крайне важно, чтобы вода не просачивалась через какое-либо неплотное соединение, в случае, если таковое окажется; should escape – форма сослагательного наклонения глагола, которая употребляется для выражения цели в придаточных предложениях-подлежащих, вводимых союзом that после, безличного оборота типа it is important, should one occur = if one should occur; should употребляется в условном предложении для выражения малой вероятности действия, обозначенного инфинитивом глагола; leak – означает: *утечка, отверстие; неплотное соединение*
** the tank is now dispensed with в этом случае обходятся без бака; (to) dispense with *обходиться без чего-либо*. Предлог with занимает место непосредственно после глагола, в силу особенностей английских пассивных оборотов.

Transformer Oil

The oil used for transformer immersion is a pure hydrocarbon (mineral) oil, obtained by refining crude petroleum. Its insulating properties are very adversely affected by the presence of even a minute proportion of water, and so it must be clean and practically free from moisture. Certain oils tend to form a sludge in the course of time, this being due to the slow formation of solid hydrocarbons. If this sludge should form on the windings themselves it tends to produce overheating. Certain high-grade qualities are called non-sludging oils, and these should be used in transformers in which the working temperature of the oil exceeds 80° C.
The use of the oil-expansion chamber reduces the tendency of the oil to form sludge, since the access of atmospheric oxygen is effectively prevented. The addition of the breather also keeps the oil dry.

CURRENT TRANSFORMERS

Why Current Transformers are Used. – A current transformer is an instrument transformer for the transformation of current from one value to another, usually a lower one, or for the transformation of current at a high voltage into a proportionate current at a low voltage with respect to earth potential. Current transformers are used in conjunction with alternating-current meters or instruments where the current to be measured is of such magnitude that the meter or instrument current coil cannot conveniently be made of sufficient carrying capacity. They are also used wherever high-voltage current has to be metered, because of the difficulty of providing adequate insulation in the meter itself. In this, connection supply voltages exceeding 660 volts are considered to be high voltage. In meter practice current transformers are used wherever the current to be metered exceeds 100 amperes, and in some instances a lower value than this is regarded as the desirable maximum for direct measurement.

Construction of Current Transformers. – A current transformer comprises a magnetic circuit, usually in the form of iron stampings assembled together to form a core, on which are wound two electric circuits called the primary winding and secondary winding respectively. The primary winding carries the current to be measured and is connected in the main circuit. The secondary winding carries a current proportional to the current to be measured and the secondary terminals are connected to the current winding of the meter or instrument. Both windings are insulated from the core and from each other. The secondary insulation is arranged to withstand a test pressure of 2,000 volts applied between the winding and the core for one minute. The insulation of the primary is arranged to withstand for one minute a test pressure applied between the primary and secondary windings approximately equal to four times the voltage existing under working conditions. During this test the core and the secondary winding are connected together.

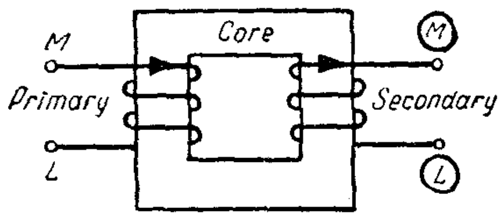

Fig. 14. Magnetic and electric circuits of a current transformer

The primary circuit of a current transformer may consist of a single conductor in the form of a bar or cable instead of a winding, when the current to be measured is of the order of 600 amperes or more. In low-voltage circuits the current to be measured may be so heavy that it is not convenient to provide a primary integral with the transformer* and the latter then consists of an iron core of appropriate shape with a secondary winding thereon, the whole being mounted on the busbar or cable. The nominal full-load current of a transformer is termed the "rated primary current" and is the value in amperes of the primary current marked on the rating plate.

The secondary winding of a current transformer is usually constructed to deliver five amperes to the meter or instrument when rated primary current flows in the main circuit. This is referred to as the "rated secondary current" and five amperes is the standard value adopted in most countries. In power-station practice it is not unusual for the meter to be separated from its current transformers by a distance of several hundred feet. The PR loss in the connecting leads together with the loss in the meter current coils may impose a burden in excess of the transformer rating if a five-ampere secondary current is adhered to. By adopting a lower value for the rated secondary current the loss in the leads can be substantially reduced and one ampere or 0.5 ampere values are permissible alternatives. Since the loss varies as the square of the current the adoption of one of these alternatives will reduce the loss in the leads to one-twenty-fifth or one-hundredth of the original value respectively.

The magnetic and electric circuits of a current transformer are represented diagrammatically in Fig. 14; the primary winding is shown surrounding one limb of the core and the secondary winding surrounding another. In actual practice the two windings would not be separated in this manner as the primary would be superimposed on the secondary, but they are shown thus for the sake of** clarity in the diagram. The primary terminals are indicated by the letters M and L, and the secondary terminals by the same letters enclosed in a circle.

The cores of current transformers are usually built up with laminations of silicon-steel but where a high degree of accuracy is desired a high-permeability nickel-steel such as Mumetal or Permalloy may be used. Three types of magnetic circuit are in common use, namely, "ring-type", "core-type" and "shell-type" and are illustrated in Fig. 15.

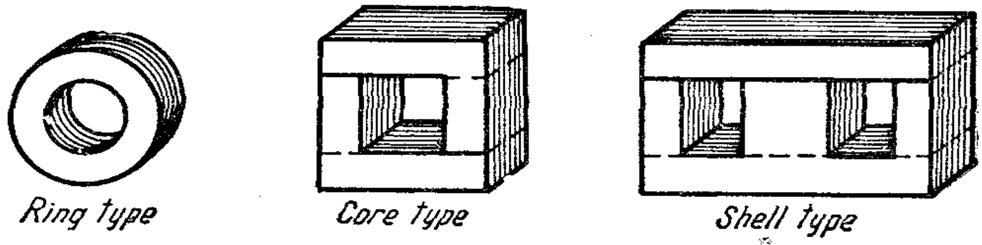

Fig. 15. Types of magnetic circuit for a current transformer

* it is not convenient to provide a primary integral with the transformer нелегко сделать так, чтобы первичная цепь составляла одно целое с трансформатором; to be integral with *составлять одно целое с ч. л., бить неотъемлемым от ч. л.*
** for the sake of (составной предлог) *ради*

VOLTAGE TRANSFORMERS

Why Voltage Transformers are Used.–When an instrument or meter having a voltage winding is connected to a high-voltage alternating-current circuit, the use of a voltage transformer (sometimes called a potential transformer) is necessary. It is not practicable to wind the voltage coil of a meter for direct connection to, say, an 11,000-volt supply, because the space available on the voltage electromagnet is not sufficient to accommodate the number of turns of wire which would be necessary. Moreover it would be quite impossible to insulate adequately the winding and the terminals in such a manner as to render the meter safe to handle when the circuit to which it was connected was alive. Accordingly, a voltage transformer is always used when a meter is installed for use on a high-voltage system. In this connection potentials in excess of 660 volts are regarded as high voltage.

A voltage transformer may be defined as an instrument transformer for the transformation of voltage from one value to another, usually a lower one. The primary winding of a voltage transformer is the winding to which is applied the voltage to be measured or controlled, as the case may be. The secondary winding is the winding the terminals of which are connected to the meter or instrument. The standard voltage at the terminals of the secondary winding is 110 volts.

Construction of Voltage Transformers.– Voltage transformers are frequently fitted in switchgear cubicles, and owing to the restricted space available the dimensions of the transformer must be kept down to a minimum. Clearances between conductors or other live parts, which in power transformer design are regarded as minimum values, cannot always be provided in voltage transformers, and as reliability is the first consideration it is only by skilful design and care in manufacture that safety can be assured.

A voltage transformer comprises a magnetic circuit, usually built, up with iron strips assembled together to form a core on which the primary and secondary windings are mounted. The primary winding which is connected to the high-voltage supply consists of a large number of turns of a fine-gauge wire* and is usually divided into a number of separate sections. The object of dividing the primary** in this manner is to limit the voltage across each section to a comparatively low value. In practice, the voltage per section does not usually exceed 1,000 volts, and frequently is much less than this figure. Each section consists of layers of wire, 3/8 in. to 3/4 in. wide, with a strip of paper or other insulating material to separate the layers. For mechanical reasons and in order to minimize the risk of breakage and open circuits, wire smaller than 36 W. G. (0.0076 in. dia.), is seldom used in the primary winding.

In voltage transformers for operation at 6,600 volts or less, it is common practice for the sections of the primary to be assembled on a tube of insulating material adjacent to the core, a second tube surrounding the sections and carrying the secondary winding. This disposition of the windings is advantageous in the case of open-type transformers since the high-voltage winding is shielded from mechanical damage by the two tubes and only the more robust low-voltage winding is exposed. For voltages in excess of 6,600 volts this arrangement is undesirable, partly because the joints between sections which are increasing in number are inaccessible, and partly because of the increasing cost of the two tubes, both of which must be capable of withstanding the full working voltage continuously. The alternative disposition in which the secondary winding is adjacent to the core and is surrounded by the primary, is more usual, a heavy tube separating the windings. Only a light tube separates the secondary from the core and no mechanical protection is provided over the high-voltage windings. This, however, is unnecessary since transformers for the higher voltages are protected by a tank or other enclosure containing oil or some other insulating medium.

Voltage transformers are made up in single units for connection to single-phase, two-phase or three-phase systems. The magnetic circuit of a single-phase voltage transformer may be of the core type or the shell type, somewhat similar in shape to the cores of current transformers. The windings are usually disposed on both limbs of the core-type carcase and on the middle limb of the shell-type. The shell-type construction is seldom employed where the system voltage exceeds 3,300 volts. Two-phase voltage transformers are required occasionally and if made up as single units, a three-limbed core is used, similar in shape to the shell-type current transformer core. The windings are disposed on the two outer limbs and as the middle limb carries the common flux for both phases It is of greater sectional area than the outer limbs. The more usual practice however is to use two separate single-phase transformers on a two-phase system. Three-phase voltage transformers are built up on three-limbed cores, all the limbs being of equal cross-sectional area. Each limb carries the primary and secondary windings for one phase of the supply, and when used for connection to a meter, the connections are usually arranged star/star.

When a transformer is switched on to a live line, the voltage between the turns of the high-voltage winding adjacent to the line terminal may be raised momentarily to a value many times the normal. A similar condition may arise as a result of switching operations elsewhere on the system and in an extreme case the voltage between successive end turns may reach a very high value; such a condition persists only for a minute fraction of a second but it imposes an additional stress on the inter-turn insulation which in the absence of precautionary measures may result in failure. The stress on the insulation is greatest between the first and second turns counting from the end of the high-voltage winding and diminishes turn by turn*** until, at some distance from the end, the abnormal stress disappears entirely.

In power transformer practice it is customary to reinforce the insulation between the end turns of the high-voltage winding and about ten per cent of the winding may be dealt with in this manner. This reinforcement is graded and is heaviest on the first few turns, but progressively less and less is added until finally reinforcement ceases, in a voltage transformer of comparable voltage, the number of turns in the high-voltage winding is very much greater than in a power transformer and reinforcement of the insulation on ten per cent of the turns would be impracticable. It is customary, however, to reinforce the insulation of the whole of the turns in the first section of the winding. As an additional precaution, a reactance coil consisting of a few turns of heavily-insulated wire is sometimes connected between the high-voltage terminal and the end of the high-voltage winding. This reactance acts like a cushion between the line and the high-voltage winding and reduces the severity of the transient stresses without adding appreciably to the dimensions of the transformer or impairing its accuracy.

* fine-gauge wire тонкая проволока (буквально – проволока тонкого калибра); wire gauge сокращенно обозначается W. G. (см. ниже в тексте)
** the primary – зд. подразумевается the primary winding первичная обмотка
* turn by turn от витка к витку

ELECTRIC CAR

The electric car is not a new idea. It had success with American women in the early 1900s. Women liked electric cars because they were quiet and, what was more important, they did not pollute the air. Electric cars were also easier to start than gasoline-powered ones. But the latter was faster, and in the 1920s they became much more popular.

The electric car was not used until the 1970s, when there were serious problems with the availability of oil. The General Motors Co. had plans to develop an electric car by 1980. However, soon oil became available again, and this car was never produced.

Today there is a new interest in the electric car. The Toyota Co. recently decided to spend $800 million a year on the development of new car technology. Many engineers believe that the electric car will lead to other forms of technology being used for transportation.

Car companies are working at developing a supercar. A super-efficient car will have an electric motor. Four possible power sources are being investigated. The simple one is batteries. Another possibility is fuel cells, which combine oxygen from air with hydrogen to make electricity. Yet another approach would be a flywheel (маховик), an electric generator consisting of free-spinning wheels with magnets in the rims that can produce a current. A fourth possible power source for the super-car would be a small turbine engine, running on a clean fuel like natural gas. It would run at a constant speed, generating electricity for driving vehicles or for feeding a bank of batteries, storing energy for later use.

ENGINES

Do you know what the first engine was like? It was called the «water wheel». This was an ordinary wheel with blades fixed to it, and the current of a river turned it. These first engines were used for irrigating fields.

Then a wind-powered engine was invented. This was a wheel, but a very small one. Long wide wooden blades were attached to it. The new engine was driven by the wind. Some of these ones can still be seen in the country.

Both of these, the water- and wind-operated engines are very economical. They do not need fuel in order to function. But they are dependent on the weather.

Many years passed and people invented a new engine, one operated by steam. In a steam engine, there is a furnace and a boiler. The furnace is filled with wood or coal and then lit. The fire heats the water in the boiler and when it boils, it turns into steam which does some useful work.

The more coal is put in the furnace, the stronger the fire is burning. The more steam there is, the faster a train or a boat is moving.

The steam engine drove all sorts of machines, for example, steam ships and steam locomotives. Indeed, the very first aeroplane built by A.F. Mozhaisky also had a steam engine. However, the steam engine had its disadvantages. It was too large and heavy, and needed too much fuel.

The imperfections of the steam engine led to the design of a new type. It was called the internal combustion engine, because its fuel ignites and burns inside the engine itself and not in a furnace. It is smaller and lighter than a steam engine because it does not have a boiler. It is also more powerful, as it uses better-quality fuel: petrol or kerosene.

The internal combustion engine is now used in cars, diesel locomotives and motor ships. But to enable aeroplanes to fly faster than the speed of sound another, more powerful engine was needed. Eventually, one was invented and it was given the name «jet engine». The gases in it reach the temperature of over a thousand degrees. It is made of a very resistant metal so that it will not melt.

DIRECT-CURRENT MOTORS

Construction. – A direct-current motor consists of the same essential parts as a direct-current generator, namely, field magnet, armature with its commutator, and brush gear. The armature and commutator are constructed on exactly the same principles as the armature and commutator of a dynamo, and any difference in external appearances of dynamos and motors is due to a modification in the mechanical arrangement of the field magnets and frame, designed to give the motor the maximum amount of protection. Dynamos are employed mostly in a central power station where they are not exposed to any mechanical danger, such as the risk of heavy bodies falling on them, and as a result they can be of open construction. This is a great advantage since they are accessible for repairs, and also they are easily ventilated.

Motors, on the other hand, often work in very exposed situations thus necessitating partial or complete enclosure of the working parts. The type of duty to be performed also has an influence on the construction of the motor. The motor must, of course, be totally enclosed, but at the same time must be capable of rapid dismantling for inspection.

General Principles.– It is often thought that the principle of operation of a dynamo is quite unconnected with that of a motor; actually the two cannot be separated, since dynamo and motor actions go on at the same time in both dynamos and motors. Any direct-current dynamo will run as a motor, that is, convert electrical power to mechanical power, if its field and armature are connected to a suitable electric supply. Also any direct-current motor will function as a dynamo provided that the conditions for self-excitation are fulfilled. In order to realize the essential connection between the two modes of operation consider the diagrams in Fig. 23. The first diagram shows one armature conductor of a dynamo rotating in a clockwise direction under a *N*. pole. Fleming's right-hand rule shows that the e. m. f. induced in the conductor acts inwards, and this also will be the direction of the current in the conductor, since, in the case of a dynamo, the current flows under the influence of the e. m. f. induced in the armature. Now whenever a current flows through a straight conductor a magnetic field is set up, the lines of force of which are concentric circles having their centre in the conductor. The direction, or sense, of these lines of force is given by the corkscrew rule, which states that if the current through a straight conductor is in the same direction as the bodily motion of a corkscrew*, then the direction in which the handle of the corkscrew has to be rotated gives the direction of the circular lines of force. Applying this rule to *A*, Fig. 23, we should have to rotate a corkscrew in a clockwise direction to drive it into the paper,** i. e. in the direction of the current in

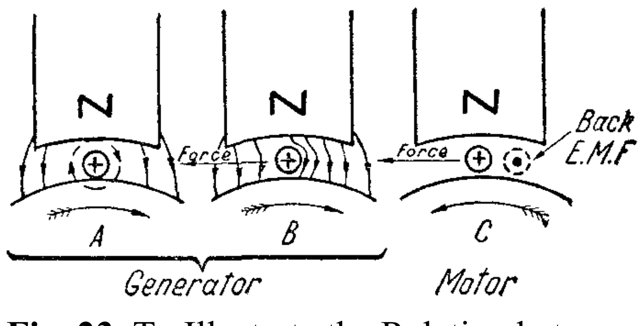

Fig. 23. To Illustrate the Relation between Dynamo and Motor Actions

the conductor, and this clockwise direction, therefore, gives the direction of the lines of force set up by the current. For simplicity only one of these lines of force is shown, and it is represented by the dotted circle. Now the lines of force of the main field from the *N.* pole cross the air-gap from the pole to the armature, i. e. downwards in the figure and, therefore, on comparing the directions of the lines of force of the two fields, we see that the armature field acts in the same direction as the main field on the right-hand side of the conductor, and in opposition to the main field on the left-hand side. As a result there is a strong field on the right-hand side and a weakened field on the left-hand side. It is impossible for two sets of lines of force to intersect one another as shown in *A*, the actual arrangement resulting from the combination of the two fields being as shown in *B*. It will be seen that some of the lines of force are bent round the conductor. Now magnetic lines of force are always in a state of tension and therefore, the bent lines of force will set up a mechanical force on the conductor much in the same way that the bent elastic of a catapult produces a mechanical force on the stone. In the case of the conductor in the figure this force obviously acts from right to left, i. e. opposite to the motion of the conductor. This applies to all the conductors on the armature of a generator delivering current, and it follows that the steam engine or other prime mover has to drag the armature round against this opposing force. For this reason the force is called the "magnetic drag."

For a current of *J* amperes flowing through a conductor of length *l* cms., placed at right angles to the lines of force of a magnetic field of strength *B* lines per sq. cm., the magnitude of the drag is given by the expression $f = \frac{BJl}{10}\, dynes$

the denominator 10 being introduced because the practical unit of cur-tent, the ampere, is one-tenth of the C.G.S. unit of current. The direction of the force is opposite to the direction of motion in the case of the generator shown in *A* and *B* and, therefore, since the right-hand rule gives the relationship between the directions of field, current and motion, a similar left-hand rule will give the relationship between field current and force. The rule is therefore as follows: hold the thumb and first finger of the left hand at right angles, and bend the second finger so as to point at right angles to the plane of these two. Then if the first finger is pointed in the direction of the field, and the second finger in the direction of the current the thumb will point in the direction of the force. This is illustrated by Fig. 24.

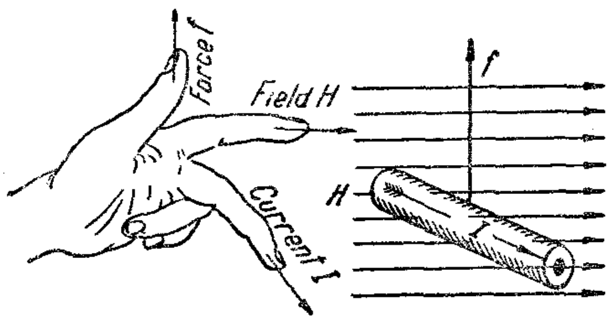

Fig. 24. To Illustrate the Left-hand Rule

Back E.M.F. – Suppose the machine, instead of generating its own electrical power, is uncoupled from the prime mover and is connected to an external supply, and current sent through the armature and field windings in the same directions as before. Then it is obvious that the magnetic fields produced by the field magnet and by the armature will be the same as before and therefore the shape of the lines of force will still be as shown in *B* Fig. 23. Therefore, the magnetic drag will be set up in the same direction as before, and since there is now no engine to force the armature round against this drag, the armature will rotate in the same direction as the drag, as shown in *C*. The machine will now be running as a motor. We therefore see that for the same direction of the armature currents and the same polarity of the field-magnets, the direction of rotation of a machine when running as a motor is opposite to its direction when running as a dynamo. On the other hand, if the directions of rotation are the same and the polarities the same, then the directions of the armature currents will be different for the two modes of operation.

Now when a machine is running as a motor, the conductors on the armature cut the lines of force of the magnetic field just as they do when the machine is acting as a dynamo. As a result they have e.m.f.'s induced in them. The direction of one such induced e.m.f. in an individual conductor is, of course, given by the right-hand rule, and applying this rule to the conductor shown in *C*, we see that the induced e.m.f. acts outwards, that is, in opposition to the current. This induced e.m.f. in the case of a motor is, therefore, called the "back e.m.f."

Application of the Principle of Work.– It is interesting to look at the above problems from another point of view. We know that an electric motor does mechanical work, and we also know that in order that any machine may do work, an equal amount of work (plus the losses in the machine) has to be put into it. Again, when the work is done some force has to be overcome. Now, it is the supply e. m. f. which puts work into the motor by driving the current through the armature, and since work is only done when some force is overcome, we see that in order that the motor may perform mechanical work, the supply e.m.f. must have some opposition. This opposition must obviously come from a force of the same nature, namely an e.m.f., from which it follows that the armature must set up a back e.m.f. A similar process of reasoning shows that a magnetic drag must be set up on the armature of a dynamo delivering current.

It will thus be seen that the motor action and the dynamo action, which for the sake of convenience are studied separately, cannot, as a matter of fact, have separate existences. They are inextricably bound up together, and one cannot come into operation without the other. As soon as a dynamo delivers current, the motor action comes into play and sets up the resistance to motion called the magnetic drag; and when a motor is made to perform work the dynamo action immediately comes into play and sets up the back e.m.f.

* the bodily motion of a corkscrew движение самого штопора; bodily – наречие в функции определения к сущ. motion.

** to drive it into the paper чтобы он (штопор) как бы ввинчивался в бумагу

POWERHOUSE AUXILIARY MOTORS

A complete description of the many and varied motor applications found in a modern steam station is almost a description of the station itself. Every phase of power generation requires some closely associated auxiliary equipment, which, in a modern power plant, is driven almost exclusively by electric motors. Indicative of the large number of motor applications in a steam station, a recent power plant comprising two 75,000-kw turbines required over 700 auxiliary motors. In a typical plant the auxiliaries consume approximately 6 percent of the total power output and have a total horsepower rating of from 12 to 15 percent of the kilowatt rating of the main turbine generators.

No two generating stations are identical. It is impossible to state exactly the motor sizes and types that will be present in a steam generating station of a particular size. The requirements are governed by such factors as type of fuel, heat cycle, source of water, and anticipated station loading cycle.

Approximate sizes of the major auxiliary motors are given later as percentages of the nominal rating of the turbine-generator unit. The figures are average values based on a survey of steam stations with turbine-generator units of 100 megawatts and below.

Characteristics of Powerhouse Auxiliary Motors.– The primary characteristics to be considered in selecting auxiliary motors are size, speed, motor type, torque requirements, operating conditions, class of insulation, and type of enclosure. In addition, motors for central-station service must have special features that insure reliability and ease of operation, features such as special moisture-resistant insulation, adequate provision for oil-ring inspection on motors with sleeve bearings, easy accessibility of the bearings and windings for servicing and inspection, and adequate terminal boxes. The reliability, efficiency, and simplicity of installation and control of the squirrel-cage induction motor have made it the almost universal choice for powerhouse applications.

Powerhouse auxiliary motors range in size from less than one horsepower, used to open and close valves, to several thousand horsepower, used to pump water into the boiler. They usually have drip-proof enclosures with class A insulation, and are designed to have low starting current and normal starting torque. However, some auxiliaries require special torque or speed characteristics, or present unusual service conditions such as excessive dirt, moisture, abrasive flyash, or high temperature; or the plant may be an outdoor installation. Motors for such applications must have special characteristics to satisfy these requirements.

Pump Motors.– Pumping is one of the major duties performed by powerhouse auxiliary equipment, and usually the largest motors in the station are those that drive the boiler-feed pumps. In a typical station the total horsepower rating of the boiler-feed-pump motors is between five and six percent of the kilowatt rating of the associated turbine. At least two and usually three boiler-feed pumps of equal rating are used. These pumps operate against a very high head of water and require 3,600-rpm driving motors.

The output of the boiler-feed pumps is controlled by throttling or by varying the speed of the pump. The latter method is attractive because of reduced operating cost. Variable-speed control, when used, is achieved with a variable-speed coupling or by using a wound-rotor motor and a liquid rheostat.

The torque requirements of boiler-feed pumps and most other pumps are satisfied by motors with low starting current and normal starting torque. Most boiler-feed-pump motors are rated for a temperature rise of 40 degrees *C* above ambient and have class *A* insulation. Where the ambient temperature is above 40 degrees, class *B* insulation is used.

Although drip-proof construction is usual, special enclosures are sometimes used to reduce the noise level of the motor or to protect the motor from flyash and other unfavorable atmospheric conditions. Noise can be reduced by using pipe- or base-ventilated motors in which the inlet and exhaust for cooling air are at a remote location. In particularly dirty locations enclosed motors are used. Air for such motors is cooled by either an air-to-air or an air-to-water heat exchanger. Since outside air is never drawn into the motor, the windings are protected from contamination.

In addition to boiler-feed pumps, numerous other pumps are associated directly with the water cycle of the plant or perform auxiliary functions. These include pumps for handling circulating water, condensate, drain water, raw water, water-purification chemicals, ash, flood water, water for fire protection, sump water, lubricating oil, and station water supply. Usually the largest of these are the circulating-water pumps. In a typical station, there are two circulating-water pumps per turbine with a total horsepower slightly less than one percent of the turbine rating. The remaining pumps range in size from a fraction of a horsepower for small chemical-feed pumps to 100 to 300 horsepower for some raw-water, ash, and fire pumps. The size of the driving motor in a particular application is determined by the head and capacity requirements, which are influenced by the nature of the water source.
The location, and the speed and torque requirements* of these pumps usually allow the use of standard drip-proof, squirrel-cage induction motors with low starting current and normal starting torque. Most pump motors have a synchronous speed of 1,200, 1,800 or 3,600 rpm; however, some motors, such as the circulating-water pumps, may require speeds as low as 277 rpm. Vertical motors are frequently used for pumping service because they require much less floor space.

THE CHILDHOOD OF THE STEAM-ENGINE

Before the Middle Ages nearly all the energy available was that of human and animal muscles, later to be supplemented by some wind and water power in the more advanced civilizations. But there were enough poor people everywhere who could be made to work for the rich and mighty, providing for their needs.

We must try to visualize these circumstances if we want to understand why science and engineering did not develop very much during the Middle Ages – why, for instance, the steam-engine was not invented, and electricity discovered, a thousand years earlier. Certainly many creative minds turned to the problem of harnessing the forces of Nature for the benefit of Man in those 'dark' centuries; but there seemed to be no need for such devices, and even if they had been invented no one would have dared to suggest how they might have been used. Life on earth, except for the chosen few, was to be a valley of tears, toil, and sweat, and any attempt at making it easier could only have been a temptation by the Devil. Scientists who dared to find out some scientific truth – for instance, that the earth is not the centre of the Universe– were made to recant, or burnt at the stake1 if they stuck to their 'heresies'.

Technical achievements do not appear out of the blue. Apart from the incentive to the inventor and the possibility of putting his inventions to some practical use, there is the development of craftmanship which plays a decisive part. For instance, the invention of the steam-engine depended on a high standard of boiler-making, which in turn meant that the craft of riveting had to be well developed. Or, to quote another example: the main achievement of a Nuremberg locksmith who lived at the beginning of the sixteenth century, was not that he 'invented the watch', as the textbook tells us, but that he was able to produce springy strips of steel, elastic enough to bend them tightly into coils. Anyone could have thought of making a pocket model of a clock, but it was the craftmanship of the locksmith which provided the essential part, the mainspring.

The frustration which an inventor must have felt when he discovered that the technological development of his time was far behind his own flight of ideas can be guessed from Leonardo da Vinci's famous notebooks. It was only late in the eighteenth century, three hundred years after Leonardo's lifetime, that his manuscripts became generally known; until then he had ranked as a great artist, but few had any idea of his importance as ah engineer and inventor. From these five thousand pages he emerges as a mechanical genius – but so far ahead of his time that most of his inventions were impossible to execute with the technological means and the craftmanship available around A. D. 1500. However, the notebooks seem to have circulated among his contemporaries, and his ideas influenced many of them. It was the time of the Renaissance, that is, of the revival of classic art and science, which marks the end of the Middle Ages and the beginning of modern times. Medieval society began to break up; a new class – that of the merchants – rose between the upper and the lower classes, and stimulated inventive thought, exploration, and expansion.

Throughout the seventeenth and eighteenth centuries numerous attempts were made at utilizing the power of steam. It was an odd succession of scientists and inventors who took up the idea every few years, now in this country, now in that: the idea of using the expanding force of water, gasified by boiling, to drive some kind of machine. There was a French architect whom Cardinal Richelieu sent to a madhouse because of the 'lunacy' of his plans; there he died after thirty years of captivity. One of his visitors at that dismal place was the Marquis of Worcester, himself a man with an inventive mind, who was also to spend a number of years behind bars. He acted as a secret agent of the exiled King Charles II until he was caught by Cromwell's men and imprisoned in the Tower of London. There he compiled his famous Century of Inventions, a collection of technical ideas, many of which were carried out long after his time: telegraph, automatic pistol, airplane, stenography, shiplifting crane, light-metal gun, megaphone, combination lock, horseless carriage, and sailless ship. Only one of his inventions – No. 68 in the Century – reached the model stage during the

Marquis's lifetime, a machine for raising water 40 feet by steam pressure in mines. Freed from the Tower by the Restoration in 1660, he was granted a patent by Parliament. The machine was exhibited as a model, but it was never executed in full size. The Marquis used a cylinder into which steam was blown and then condensed; the resulting vacuum would suck the cylinder full of water after a valve had been opened. By blowing in some more steam the water could be forced out of the cylinder, and the cycle restarted.

It may seem surprising that even in the seventeenth century, when the superstitious and reactionary forces of medieval society had lost much of their hold over the minds of men technical progress was so slow and inventive ideas so rare. Even the Marquis of Worcester must have suffered from some feeling of guilt; he wrote, in connection with his water-raising machine, that he prayed to Providence to punish him for his arrogance and for yielding to evil temptations.

Perhaps the most interesting personality among the seventeenth-century steam-engine inventors was Denis Papin, a French Huguenot, who studied medicine and physics as a young man. He met the great Dutch scientist Christian Huygens, inventor of the pendulum clock and author of the wave theory of light, in Paris and went with him to the Hague. They worked together for eight years, and then Huygens recommended the young Frenchman to Robert Boyle, the famous English physicist, whose special field was the pressure of gases.

From 1675, Papin lived in Boyle's house in Pall Mall, London, and here he made an invention which has only recently become popular in the kitchens of the world – the pressure cooker. It was the outcome of his investigations into the nature of steam.

Papin's 'bone-digester', as he called his machine, worked on the principle that when water or juice is boiled in a hermetically closed vessel so that the steam cannot escape, the pressure increases so much that the steam is heated far beyond the boiling-point of water. The superheated steam helps to cook the food much faster and more thoroughly than is possible in ordinary saucepans. 'I took beef bones that had never been boiled, but kept dry a long time,' Papin wrote in the description of his first experiment, 'and of the hardest part of the leg; these being put into a little glass pot, with water, and inserted in the engine.' He also invented the safety-valve, a little stopper with a weight attached, which closed a hole in the pot so long as the pressure did not increase beyond a certain point; when it became too great it forced the stopper out, and some steam escaped. This invention alone would have established his fame in the annals of technical history, for it was the first automatic control device.

Papin introduced his bone-digester to the scientists of the Royal Society by cooking a meal for them. It was excellent, and they enjoyed this 'scientific dinner', as Papin called it, very much. But he made it plain to them that he regarded his bone-digester merely as a stepping stone to the steam-engine which he hoped to build one day.

A political event of great importance interfered with Papin's plan to return to his native country and continue his work there. Louis XIV revoked the Edict of Nantes, that solemn garantee assuring the Huguenots of religious freedom. Denis

Papin had become an exile.

At this turning-point in his life, a German Protestant prince offered him a chair at the University of Marburg. Papin accepted, hoping that under the protection of an enlightened ruler he would be able to develop his steam-engine; his pet idea was that of driving a ship with it 'against the wind'.

He built an experimental model at Marburg. It was a complicated and rather clumsy machine whose energy derived more from atmospheric pressure than from the power of the expanding steam; a workman had to solve a fire-box under it at certain intervals to produce the steam, and remove it again to cause condensation. But it had one ingenious feature which pointed the way to a really efficient prime mover: Papin used the cylinder and piston of a pump in his design. This, above all, was Papin's most valuable contribution to the development of the steam-engine.

He described his invention in a pamphlet published in 1690, hopeful that the whole world would acclaim him as its benefactor. But the world seemed to have little use for the steam-engine; only one inventor, an English captain by the name of Thomas Savery, carried out some of Papin's ideas and took out a patent for a water-lifting machine.

So Papin decided to return to England, where he hoped to find more support. He bought a boat and fitted it with paddle-wheels, later to be driven by steam power; but as a kind of propaganda act Papin intended to propel it by means of hand-cranks from Marburg all the way to England, with his wife and his numerous children on board.

He did not get very far. A few miles down the river, at the next town, the watermen's guild barred the way to the strange vessel full of foreigners. There was a tussle, the irate scientist tried to push on, but the watermen pulled the boat on land and cut it to pieces with their pickaxes.

Desperate and without a penny to his name Papin arrived back in London. In vain he tried to get the Royal Society to help him build his steam-engine, or at least: compare his designs with those of Savery. In the end he had to struggle for a bare livelihood. His traces are lost in the slums of London; the last document in his handwriting, a letter to a friend, dates June 1712, closes thus:

'I am in a melancholy situation; in spite of all my effort I only bring down enmity on myself. But I have no fear.'

In the same year an ironmonger and Baptist preacher from Dartmouth, Thomas Newcomen, completed his own steam-engine after years of experimenting with Savery's pumps. The only place where such an engine was urgently needed was in Britain's mines, which filled with water faster than it could be cleared out. Savery had used the method of creating a partial vacuum in the cylinder by dashing cold water on its outside, thus causing the steam inside to condense; Newcomen, however, sprayed the cold water directly into the steam-filled cylinder to create a vacuum so that the atmospheric pressure forced the piston down. From the time of Savery's death in 1715, Newcomen controlled the manufacture of steam pumps in Britain for a good many years. Some were exported to the Continent although they wasted an enormous amount of coal and had to.have constant attention.

Newcomen machines were the only practical steam-engines from the early to the late eighteenth century; a few improvements were made in Scotland. One of the largest Newcomen engines went to Russia in 1775 to pump out the dry docks at Kronstadt.

MICHAEL FARADAY

Faraday (1791 – 1867) was one of the ten children of a blacksmith, who moved with his family to London. It is a rare labouring family with ten children that is rich, so there was no question of an education for young Faraday and he was apprenticed to a bookbinder.

This, as it happened, was a stroke of luck, for lie could read books there. Faraday's second stroke of luck was that his employer was sympathetic to the young man's desire for learning and allowed him to read books and to attend scientific lectures.

In 1812 a customer gave Faraday tickets to attend the lectures of Humphry Davy at the Royal Institution. Young Faraday took careful notes which he further elaborated with coloured diagrams and these he sent to the president of the Royal Society in the hope of getting a job that would bring him into closer contact with science. Getting no answer he sent others to Davy himself along with an application for a job as his assistant. Davy was enormously impressed by the clear ability of the youngster. When an opening as his assistant occured, he offered the young man the job. Faraday took it in 1813, at the age of twenty-two – at a salary that was smaller than the one he had been earning as a bookbinder. Almost at once Davy left for his grand tour of Europe and look Faraday with him as a secretary.

Faraday became director of a laboratory in 1825, and in 1833 the one-time bookbinder's apprentice became professor of chemistry at the Royal Institution.

In chemistry Faraday made his first mark in 1823, when he devised methods for liquefying gases under pressure. He was the first to produce temperatures in the laboratory that were below the zero mark of the Fahrenheit scale. He may just be viewed as a pioneer in the modern branch of physics called cryogenics (the study of extreme cold).

In 1825 occured his greatest single contribution to organic chemistry. He discovered benzene, a compound that was to piny a key role in the development of a means of representing molecular structure.

In 1833–1834 Faraday further reduced the matter of[5] electrolysis to quantitative terms by announcing what are now called Faraday's laws of electrolysis. Faraday's laws put electrochemistry on its modern basis. In his honour the quantity of electricity required to liberate 23 grams of sodium, or 108 grams of silver or 32 grams of copper (that is, to liberate an "equivalent weight" of an element) is called a farad. Also, the unit of electrostatic capacitance is the farad, in his honour.

In later years Faraday made more discoveries in connection with electromagnetism and its interaction with light.

When he was eventually offered the presidency of the Society by Tyndall, however, he declined it and he also declined an offer of knighthood. He was intent on being plain Michael Faraday.

JAMES MAXWELL

In the decade 1860–1870, James Maxwell formulated his classical electromagnetic theory. He showed that light was a form of wave motion travelling with a speed dependent on the electric and magnetic properties of the medium through which it is transmitted, lie also predicted that waves longer than those of light could exist.

Even before Maxwell advanced the theory that electromagnetic waves should exist, men were making use of them for other purposes besides vision. For instance, the short ultraviolet rays in sunlight provided suntans; and the heat of the sun – provided by the long infra-red rays – was often concentrated by means of a lens to start fires. After the existence of electromagnetic waves had been proved by Hertz it was discovered that they range in length from hundreds of miles down to less than a billionth of an inch. The long waves could be used to carry sounds through space; as a consequence radio was developed.

A more recent development, which is related to radio, is television. Not only sounds but pictures can be transmitted at a distance because of electromagnetic waves.

Another modern device, developed to send out electromagnetic waves and to receive the echoes when they return, is radar, since the speed of electromagnetic waves is known, the time it takes for an echo to return to the radar set can tell the operator how far away a plane is from his set. Radar is given the credit for saving Great Britain during World War II, for it warned of enemy planes. Thus James Maxwell had made discoveries that later protected his homeland. Today with radio, television, radar, and communication with outer space making use of these waves, it is easy to realize why James Maxwell is now considered one of the great scientists of all time.

BALL LIGHTNING

It is quite probable that there are several different physical forms of ball lightning, each having its own characteristic set of properties. These phenomena are rare and this rarity leads to the wide variety of descriptions of ball lightning.

Lightning balls seem to appear near the end of severe electrical storms. This happens after the air has been highly ionized and is filled with electromagnetic disturbances generated by the conventional lightning.

The diameters of observed lightning balls range from a few inches to rare instances of many feet. The average diameter of a ball is about 10 inches. The balls usually move by rolling or sliding along conductors such as telephone wires, fences, and other metallic objects.

The lifetime of a ball of lightning may range from a few seconds to minutes.

One large ball was observed to hang near the base of a cloud for 15 minutes. The calculated surface temperature of a lightning ball can be as high as 5,000°C. When the ball decays, a great amount of energy is released.

The Soviet physicist Pyotr Kapitsa was the first to present a reasonable explanation for the majority of the questions in a hypothesis for ball lightning. His ideas on the energy balance, on the importance of resonance phenomena, and on the fixed dimensions of "ball lightning are, well known. The theory put forward by him in 1955 starts with the description of a powerful flash of lightning at the end of a thunderstorm. It paves the way for the appearance of ball lightning at sufficient ionization of the air and the presence of vapours necessary for ionization of the rising current of air. The ionized clouds of plasma are composed of the atomic nuclei of gas stripped of their electrons. These nuclei possess their own 'periods of electromagnetic oscillations and are able to absorb the incoming external electromagnetic energy of the same period. This is known as the resonance effect.

Details of Kapitsa's hypothesis include the reasoning that during the luminescence period, some energy is supplied continuously into the ball lightning and the energy source is outside the ball. This reasoning is based on the conservation of energy principle and on the realization that the ball lightning is suspended in the air with no visible link with the energy source* Thus the only source of energy is the absorption of intense outside radio waves. The resonance characteristic of the absorption process is determined by the form of the ball lightning alone and by its dimensions. For effective absorption of radio waves by the lightning ball, the natural frequence of the electromagnetic oscillations within the ball, must coincide with the natural period of the absorbed radiation.

As to academician Kapitsa, his field of interests was not limited by high temperatures alone. In 1978 he was given a Noble prize for his fundamental discoveries and inventions in the field of low temperatures and superconductivity.

EDISON'S LIGHTING SYSTEM

It was only in the last quarter of the nineteenth century that electricity began to play its part in modern civilization, and the man who achieved more in this field of practical engineering than any of his contemporaries was the American inventor, Thomas Alva Edison. His dramatic career is too well known, and has been described too often, to be told again; it may suffice to recall that he became interested in the problem of electric lighting in 1877, and began to tackle it with the systematic energy which distinguished him from so many other inventors of his time. Edison was no scientist and never bothered much about theories and fundamental laws of Nature; he was a technician pure and simple, and a very good business man as well.

He knew what had been done in the field of electric lighting before his time, and he had seen some appliances of his contemporaries, such as the arc-lamp illuminations which had been installed here and there. Two sticks of carbon, nearly touching, can be made to produce an electric arc which closes the circuit. Many scientists and inventors who tried to tackle the problem were therefore convinced that only incandescent electric light – produced by some substance glowing in a vacuum so that it cannot burn up – could ever replace gas lighting, then the universal system of illumination in Europe and America.

Edison put his entire laboratories at Menlo Park to the task of developing such a lamp. The most important question was that of a suitable material for the filament. He experimented with wires of various metals, bamboo fibre, human hair, paper; everything was carbonized and tried out in glass bulbs from which the air had been exhausted. In the end – it is said that a button hanging loose from its thread on his jacket gave him the idea – he found that ordinary sewing thread, carefully carbonized and inserted in the airless bulb, was the most suitable material. His first experimental lamp of 1879 shed its soft, yellowish light for forty hours: the incandescent electric lamp was born.

It was, no doubt, one of the greatest achievements in the history of modern invention. Yet Edison was a practical man who knew well that the introduction of this revolutionary system of illumination must be properly prepared. He worked out methods for mass-producing electric bulbs at low cost, and devised circuits for feeding any number of bulbs with current. He found that 110/220 volts was the most suitable potential difference and would reduce transmission losses of current to a minimum – he could not have foreseen that the introduction of that voltage was to set the standard for a century of electric lighting. But most important of all 'accessories' of the lamp was the generator that could produce the necessary high-tension current.

Since Faraday's ingenious discovery of the way in which movement could be transformed into electricity, only a small number of engineers had tried to build generators based on this principle. But none of these generators answered the particular requirements of Edison's electric light; so he had to design his own generator, which he did so well that his system – apart from minor improvements and of course the size of the machines – is still in general use today.

It is little known that the first application of Edison's lighting system was on board an arctic-expedition steamer, the Jeannette, which the inventor himself equipped with lamps and a generator only a few weeks after his first lamp had lit up at Menlo Park. The installation worked quite satisfactorily until the ship was crushed in the polar ice two years later.

Edison, a superb showman as well as a brilliant inventor, introduced his electric lamp to the world by illuminating his own laboratories at Menlo Park with 500 bulbs in 1880. It caused a sensation. From dusk to midnight, visitors trooped around the laboratories, which Edison had thrown open for the purpose, regarding the softly glowing lamps with boundless admiration. Extra trains were run from New York, and engineers crossed the Atlantic from Europe to see the new marvel. There was much talk about the end of gas-lighting, and gas shares slumped on the stock exchanges of the world. But a famous Berlin engineer – none other than Werner von Siemens, who later became Edison's great rival in central Europe – pronounced that electric light would never take the place of gas. When Edison showed his lamps for the first time in Europe, at the Paris Exhibition of 1881, a well-known French industrialist said that this would also be the last time.

Meanwhile, however, Edison staked his money and reputation on a large-scale installation in the middle of New York. He bought a site on Pearl Street, moved into it with a small army of technicians, and built six large direct-current generators, altogether of 900 h. p., powered by steam-engines. Several miles of streets were dug up for the electric cables – also designed and manufactured by Edison – to be laid, and eighty-five buildings were wired for illumination. On 4 September 1882 New Yorkers had their first glimpse of the electric age when 2,300 incandescent lamps began to glow at the throwing of a switch in the Pearl Street power station. Electric lighting had come to stay. And what was most important: Edison had finally established a practical method of supplying electricity to the homes of the people.

Pearl Street was not the first generator station to be built. A 1-h. p. generator for the supply of current for Edison lamps was built in 1881. In Germany, Werner von Siemens did more than any other engineer for the introduction of electric lighting, in which he had first refused to believe, by perfecting his 'dynamo', as he called the generator for continuous current.

Spectacular as the advent of electric lighting was, it represented only one aspect of the use of electricity, which was rapidly gaining in popularity among industrial engineers. For a century, the reciprocating steam-engine had been the only important man-made source of mechanical energy. But its' power was limited to the place where it operated; there was no way of transmitting that power to some other place where it might have been required. For the first time, there was now an efficient means of distributing energy for lighting up homes and factories,, and for supplying engines with power.

The engine which could convert electric energy into mechanical power was already in existence. As early as 1822, nearly a decade before he found the principle of the electric generator, Faraday outlined the way in which an electric motor could work: by placing a coil, or armature, between the poles of an electromagnet; when a current is made to flow through the coil the electro-magnetic force causes it to rotate – the reverse principle, in fact, of the generator.

The Russian physicist, Jacobi built several electric motors during the middle decades of the 19th century.

Jacobi even succeeded in running a small, battery-powered electric boat on the Neva river in St. Petersburg. All of them, however, came to the conclusion that the electric motor was a rather uneconomical machine so long as galvanic batteries were the only source of electricity. It did not occur to them that motors and generators could be made interchangeable.

In 1888, Professor Galileo Ferraris in Turin and Nikola Tesla – the pioneer of high-frequency engineering – in America invented, independently and without knowing of each other's work, the induction motor. This machine, a most important but little recognized technical achievement, provides no less than two-thirds of all the motive power for the factories of the world, and much of modern industry could not do without it. Known under the name of 'squirrel-cage motor'[1] – because it resembles the wire cage in which tame squirrels used to be kept – it has two robust circular ;rings made of copper or aluminium joined by a few dozen parallel bars of the same material, thus forming a cylindrical cage. It is built into an iron cylinder which is mounted on the shaft, and forms the rotor, the rotating part of the machine. It is exposed to a rotating magnetic field set up by the stator, the fixed part of the machine, consisting of many interconnected electrical conductors called the winding. The relative motion between the magnetic field and the rotor induces voltages and currents which exert the driving force, turning the 'cage' round.

Although the induction motor has been improved a great deal and its power increased many times over since its invention, there has never been any change of the underlying principle. One of its drawbacks was that its speed was constant and unchangeable. Only in 1959 did a research team at the University of Bristol succeed in developing a squirrel-cage motor with two speeds – the most far-reaching innovation since the invention of the induction motor. The speed-change is achieved by modulating the pole-amplitude of the machine.

From the day when Edison's lamps began to glow in New York, all the world asked for electricity. Already a year earlier, Werner von Siemens had succeeded in coupling a steam-engine directly to a dynamo. But the engineers had their eyes on another, cheaper source of mechanical power than the reciprocating steam-engine: that of falling water. We do not know which of them suggested the idea of a hydro-electric power station for the first time; it was probably very much 'in the air'. Back in 1827, a young Frenchman, had won the first prize in a competition for the most effective water turbine in which the water would act on the wheel inside a casing instead of from outside. It was one of the prototypes of the modern water turbine. In the 1880's, an American engineer designed a turbine wheel with enormous bucket-shaped blades along the rim, and a few American towns with waterfalls installed these turbines coupled to Edison generators. This type proved especially efficient where the fall of water was steep but its quantity limited; for a low fall of water the turbine – with only four large blades proved better suited. However, the type which appeals most[5] to the engineers is now the turbine for falls of water from 100 to 1,000 feet, with a great number of curved blades. The power station which convincingly showed the enormous possibilities of hydro-generated electricity was the one at Niagara Falls, begun in 1891, and put into operation a few years later with an output of 5,000 h. p. – it is 8 millions h. p. today.

The early power stations generated direct current at low voltage, but they could distribute it only within a radius of a few hundred yards. The Niagara station was one of the first to use alternating current (although the sceptics prophesied that this would never work), generated at high voltage; this was transmitted by overhead cables to the communities where it was to be used, and here 'stepped down' into lower voltages (110 or 220) for domestic and industrial use by means of transformers. High-voltage transmission is much more economical than low-voltage; all other circumstances being equal, if the transmission voltage is increased tenfold the losses in electric energy during transmission are reduced to one-hundredth. This means that alternating current at tens or even hundreds of thousands of volts, as it is transmitted today, can be sent over long distances without much loss.

These ideas must have had something frightening to the people at the end of the last century, when electricity was still a mysterious and alarming novelty. The engineers who built London's first power station, with a 10,000-volt generator, in 1889, and their German colleagues who set up a 16,000-volt dynamo driven by a waterfall in the River Neckar, to supply Frankfurt, 100 miles away, with electricity in 1891 – these men must have felt like true pioneers, derided, despised, and abused by the diehards. There were, of course, also some powerful commercial interests involved, for the gas industry feared for its monopoly in the realm of lighting– and with a good deal of justification as it turned out.

THE GREAT INVENTION OF JAMES WATT

By the middle of the 18th century, however, the childhood of the steam-engine was already drawing to an end. A young Scotsman by the name of James Watt, the fifth son of a ship's carpenter gave the machine its most efficient form – and thereby helped to revolutionize the British way of life.

He was a weakly child, suffering from headaches and unable to go to school. His mother taught him, and as soon as James could read he began to devour books. At the age of 15 he had learnt most of what was then known about physics, and his father sent him to Glasgow to study advanced mechanics. Later, his professor helped him to set himself up as an instrument-maker and 'machine-doctor' in a shop in the University building.

One day in 1763 –Watt was 27 years old –he was asked to repair a small model of a Newcomen engine,which was needed for the natural-science lectures. The little machine refused to work properly, stopping again and again after a few strokes of the piston.

Watt examined it carefully. It had a boiler in which the steam was produced. At the bottom of the cylinder were two valves, one to admit the steam and the other to let a jet of cold water cool the cylinder when the piston had reached its highest point This caused the steam to condense – and as steam takes up 1,700 times more space than water a vacuum was created under the piston, and it was forced down by the pressure of the atmosphere.

It was clear to Watt's inquisitive mind that this machine, even when in perfect working order, used the steam not nearly efficiently enough. Was there, he asked himself, sonic better way of making the piston move? The cold-jet injection seemed too clumsy to him.

For two years he tried to find a solution to the problem. 'One Sunday afternoon in 1765, he recalled later, 'I had gone for a walk and my thoughts turning naturally to the experiments I had been engaged in for saving heat in the cylinder, 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 this and the steam in the cylinder, such would be the result.'

It was this idea of the separate condenser which made the steam-engine the first great prime mover in modern times. Now the cylinder could remain hot, without having to be cooled and reheated with each cycle; he even put a steam jacket around of the fuel which the Newcomen engine needed. He also closed the upper end of the cylinder, which was open in the Newcomen engine, and built around the piston rod what is now called a stuffing-box; instead of making the air push the piston down he used steam for this purpose too, introducing it above the piston as well as below in the cylinder. The fourth of his improvements was an air pump to maintain the vacuum on his condenser by pumping out the condensed water and air from it.

Watt's first model was single acting and could be used only for pumping. But a great many tasks were awaiting the steam-engine. New machines in various branches of industry needed power; goods were to be moved, people transported.

A manufacturer from Soho, near Birmingham, Boulton, made James Watt his partner in the world's first steam-engine factory. Soon the firm of Boulton & Watt became one of the wonders of the age: here the visitors, who turned up from all over Europe and even America, could see the shape of things to come.

Boulton made Watt think of ways and means to convert the reciprocating movement of the engine into a rotary one for use in factories and, later perhaps, for vehicles and ships. Watt produced no less than five different solutions, the best of them being the 'sun-and-planet' system – we are so familiar with it that we hardly realize what an excellent solution to a tricky problem it is. Watt also adopted an old invention, the fly-wheel, for the important purpose of turning the irregular motion of the piston into a regular, rotary one. The fly-wheel is, in fact, a reservoir of energy, which it 'stores up' during the working stroke of the engine, to release it as the crank passes through the dead centre.

Neither could he have known that he invented one of the major 'feed-back' devices–which play such a vital part in automation, where they act as automatic controls. This is the 'governor', whose task it is to keep the engine speed constant, detect an unnecessary or dangerous increase of engine power, and to reduce it by closing the throttle or steam-valve. The Watt governor works simply by using centrifugal force: a vertical shaft, carrying two heavy metal balls at the ends of arms, is rotated by the engine, and centrifugal force moves the balls outwards as the engine speed increases, or allows them to sink as the speed decreases. The arms to which the balls are fixed move therefore up or down, raising or lowering a 'collar' around the vertical shaft. This is connected to the throttle or steam-valve, closing or opening it if the engine speed becomes too great or too low. Thus the steam-engine controls itself.

'The people of London, Manchester, and Birmingham are steam-mill mad', Boulton told Watt in 1781. The Soho factory turned out as many steam-engines as possible, yet the demand surpassed by far its production capacity, and other manufacturers' were permitted to build them under Watt's licence. Why was there now such an enormous demand for energy, after centuries of indifference and even hostility towards the idea of Using the forces of Nature for benefit of mankind?

Slowly, the medieval system of the individual craftsman had begun to crumble. In England a new form of industry appeared, timidly at first: groups of men banded together to use machines which were too costly and too heavy for the independent artisan. Merchants' who needed wares to sell provided the money and organized the manufacture, or 'factory'. These 'capitalists' employed the workers for wages. They appeared first in those trades where heavy machinery and capital was most necessary: mainly in coal-mining, where the early steam pumps saved many pits from ruin through flooding, and in textile production, where a number of inventions were revolutionizing spinning and weaving.

It was through the impact of these new machines that Britain hitherto a nation of farmers, turned into an industrial state – and that Englishmen left the countryside by their many, thousands to crowd into the towns[1] and seek employment in the factories which seemed to promise work and livelihood for all. Spinning and weaving, a most important industry in a cold, northern climate had been carried out in the villages with spinning-wheels and hand looms; but although the cloth produced in this way was expensive, the men and women who made it lived in poverty from the cradle to the grave. Only a substantial rise in the level of production could have increased the country's standard of living. Taxes took away much of the people's earnings, and feudal restrictions prevented a free exchange of goods and services.

The new machines broke through this barrier, changing an old-fashioned handicraft to modern mass production. John Kay, a poor clockmaker from Lancashire, made the beginning with his 'fly shuttle', a little box on either side of the loom, where the shuttle remained between its journeys across the warp threads. Each box had a little rod, one end of which was fastened to a cord, and when the cord was pulled the rod hit the shuttle and shot it across the loom into the little box on the other side. Then the cord on the other side was pulled, and the shuttle flew back again. Thus the weaver– instead of throwing the shuttle across and back again by hand – could work much faster, and the width of the cloth could be doubled.

John Kay made his invention in 1733. Thirty-five years later, a weaver, James Hargreaves invented a spinning machine – which he called 'Spinning Jenny' after his wife –with eight spindles operated by a single wheel. Later he built a machine with thirty spindles. Richard Arkwright, a barber by profession, heard the weavers in his home town complain that the yarn produced by the new spinning-jenny was not as fine and smooth as that spun by the old method. With the help of a watch-maker he built a new machine which squeezed the wool or cotton into long, flat strands and then twisted them into smooth threads. The machine was good but heavy and could be worked only by power; as it was first worked by water power it became known as the 'water-frame'.

At the turn of the century a young university graduate from Massachusetts, Eli Whitney revolutionized cotton harvesting by his invention of the 'cotton gin'. Negro slaves had been used in the southern states of the USA to separate the fibre from the seeds by hand; the gin did it mechanically. It was this machine which influenced the development of the whole of the United States more than any other; cotton became the country's great source of wealth. When Whitney first introduced his machine, the USA produced no more than 140,000 lb. of cotton per year: in 1800, only a few years later, the figure was 35 million pounds.

All these inventors had to struggle hard against prejudice and fear, most of all among the workers, who were worried about losing their jobs when those new machines would start to produce more and more goods. There were riots, some inventors were driven out of the country, others died penniless. But the men who built the new factories saw that these machines could offer them enormous profits. They installed them, bought steam-engines to power them, and the workers had to come willy-nilly to ask for jobs in the factories if they wanted to make a living. Wages were low, conditions in the 'dark satanic mills' usually deplorable, working hours long – up to fourteen hours per day – and many children went into factories to toil with their parents so that the family would have enough to eat.

When James Watt retired from the firm of Boulton & Watt at the age of 64 in 1800, steam-engines were already puffing and hissing all over Europe, and even in America. For the first time in human history, the immense storehouse of the earth's mineral wealth had been unlocked to provide its inhabitants with mechanical power. The consequences were far-reaching. Not only because the steam-engine was a British invention but also because Britain was particularly rich in coal, this country was the first to undergo an industrial revolution which changed the whole way of life completely within the time of two or three generations. As agricultural Britain became industrial Britain, the power of the landowning class began to weaken and the middle classes – the producers and distributors of goods – rose in importance and wealth. In her quickly growing Empire, England found many sources of new materials for her factories – and cheap labour to reap a rich harvest; until the 1830's, tobacco, sugar, and cotton were almost exclusively produced by coloured slaves.

As the use of steam power became general it was found necessary to set a standard for determining the capacity of engines. People were still familiar with the horse as a source of power, and so it was natural to compare the power of a steam-engine with that of a horse. Boulton & Watt standardized one horsepower at 33,000 foot-pounds per minute, or 550 foot-pounds per second – i. e. the power necessary to lift 550 lb. one foot per second (or 1 lb. 550 ft per second). Later, when electricity became important for the transmission of energy, James Watt's name was honoured by the acceptance of the watt as unit of electrical power. The relationship between horsepower and watt is that 746 watts are 1 h. p., and 1 kW (1,000 W) = l -36h.p.

Eli Whitney, the inventor of the cotton gin, was also responsible for the first application of mass production methods. The United States Army needed muskets because there was some danger that there might be a war with France. Eli Whitney accepted in 1798 a contract for the delivery of 10,000 muskets within fifteen months. They could never have been made by the traditional methods, with one gunsmith making the complete musket from start to finish. So Whitney had the idea of dividing up the work into a great number of small jobs, as a result of which all the component parts of the musket would be made so accurate as to be interchangeable. It was a completely new system.

He brought his first batch of ten muskets to the United States Treasury officials in Philadelphia, but he did not show them the complete weapons – he brought parcels with the component parts, and asked them to pick the parts from each batch at random. From these components he assembled the muskets before their eyes. It was the first demonstration of the system of interchangeable parts, made by semi-skilled workers in mass production.

Whitney carried out his contract with the help of a small number of men. But he used a water-mill as his main source of power in the factory which he built near New Haven. Legal battles and troubles concerning his cotton gin as well as increasing ill health sapped his energy and shortened his life; otherwise he would certainly have become America's first industrial king, ruling over an empire of steam-powered engineering works.

During the comparatively short time of thirty-five years the genius of James Watt improved the reciprocating steam-engine so much that throughout the nineteenth century this prime mover remained basically as he had shaped it – although it increased a great deal in size, performance, and accuracy of construction.

THE DEVELOPMENT OF ILLUMINATION

Perhaps we might in this connection give a brief sketch of the development of illumination. From his earliest times, Man has had an intense dislike of the dark. Besides, as soon as he had learnt how to use his brain the long winter nights with their enforced idleness must have bored him. Lightning, the fire from heaven, gave him the first 'lamp' in the shape of a burning tree or bush. He prolonged the burning-time of firewood by dipping it into animal fat, resin, or pitch: thus the torch was invented. It was in use until well into the nineteenth century; many old town houses in England still have torch-holders outside their front doors, where the footmen put their torches as their masters and mistresses stepped out of the carriages.

Rough earthenware, oil lamps were in use in the earliest civilizations; these lamps, though much refined, were still quite common a hundred years ago. The Romans are usually credited with the invention of the candle, originally a length of twisted flax dipped in hot tallow or beeswax which later hardened as it cooled off. Candles were at first expensive, and only the rich and the Church could aitord them. As late as the 1820's, stearin candles – cheap and mass manufactured – came into use, and still later they began to be made of paraffin wax.

By that time, however, a new kind of illumination had been introduced all over the civilized countries: gaslight. In the 1690's an English scientist Dr. John Clayton observed that the gases which developed in coal-pits and endangered the lives of the miners were combustible. He experimented with pieces of coal, which he 'roasted' over a fire without allowing them to burn up, and found that the resulting gas gave a pleasant, bright flame. German and French chemists repeated his experiments, but a hundred years passed after his discovery before gas became a practical form of illumination.

William Murdock, a Scotsman who started his career as a mechanic, took up Clayton's idea. He built an iron cauldron in his cottage garden and heated coal in it. This 'incomplete combustion' produced a mixture of highly inflammable carbon monoxide and nitrogen. He piped the gas into his house and fixed taps in every room. Many a night the people of Redruth stood in silent awe around Murdock's cottage, gazing at the wonderful new lamps which shed a bright light throughout the house.

After two years of experimenting", he persuaded his employer, Watt, to let him illuminate the Soho factory by gaslight. The installation was completed just in time to celebrate the peace treaty of Amiens and the end of the Anglo-French war in 1802 with the first public exhibition of gaslighting in and around the factory.

A year later, gaslight came to London. The people of the capital saw for the first time a street bathed in light at night. But many people were against it.

'London is now to be lit during the winter months with the same coal-smoke that turns our winter days into nights,' complained Sir Walter Scott, and even such an eminent man as Sir Humphry Davy exclaimed that he would never acquiesce in a plan to turn St. Paul's into a gasometer.

But the progress of gaslighting could not be stopped; the main argument for it was that it would increase public safety in the streets– it took much longer to persuade the people that there was no danger to their homes if they had gas tubes laid into them.

The introduction of gaslight in the factories had an especially far-reaching effect – it made the general adoption of night shifts possible. The first industry to do this was the Lancashire textile industry, for the workers at their looms were now able to watch the threads at any time of the day or night.

Murdock's assistant was responsible for many improvements; among other things he invented the gas meter, and put up gas lamps on Westminster Bridge in 1813. Three years later, most of London's West End was already gaslit, and by 1820 nearly all Paris. New York followed in 1823. In Germany there were many objections to be overcome until the advantages of gaslight were recognized.

William Murdock lived long enough to witness the beginning of another development whose importance few people recognized at the time: gas cooking. In 1839 the first gas-oven was installed at a hotel, and a dinner cooked for a hundred guests. For a long time, however, this idea did not catch on. But when towards the end of the century the electric light began to take over from the gas lamp, the industry was forced to make a new effort so as not to be squeezed out of existence. In 1885 the Austrian physicist Carl Auer introduced his incandescent gasmantle, which quickly superseded the open (and dangerous) gas flames which had until then been in use. He used the same principle as Edison in his electric lamp; his gas-mantle was a little hood of tulle impregnated with thorium or cerium oxide. For a while, incandescent gaslight gained ground, and many people who had already installed electric cables had them torn up again. But in the end electricity won because it was more effective and more economical.

Only then did gas cooking emerge as a new aid to the world's housewives. It has still its place in the kitchen; gas-operated refrigerators, gas stoves, and central-heating systems are more recent developments. Gas has by no means outstayed its welcome[3] in our civilization.

Auer himself was responsible for one of the decisive improvements in the electric bulb, the great rival of his gas lamp. Using his experience with rare earths he developed a more efficient filament than Edison's carbonized thread-osmium. It was superseded in its turn by the tungsten "wolfram" filament, invented by two Viennes scientists in the early 1900's. Since about 1918, electric bulbs have been filled with gas; today, a mixture of argon and nitrogen is in general use.

Is the incandescent lamp now also on its way out? In innumerable offices, factories, public buildings and vehicles, and a good many homes (especially in the kitchens) the fluorescent lamp has taken over from it. This is based on two scientific phenomena that have long been known: that certain materials can be excited to fluorescence by ultra-violet radiation, and that an electric discharge through mercury under low pressure produces a great deal of invisible ultra-violet radiation. Professor Becquerel, grandfather of the scientist whose work on uranium rays preceded the discovery of radium, attempted to construct a fluorescent lamps as long ago as 1859 by using a discharge tube. American, German and other French physicists worked on the same lines, and eventually the new type of lamp found its first applications for abvertising (neon light). The difficulty was the production of a daylight-type of light with sufficient blue in its spectrum.

The modern fluorescent lamp consists of a long, gas-filled glass tube, coated inside with some fluorescent powder; this lights up when excited by the invisible ultraviolet rays of an arc passing from the electrode at one end to that at the other. Strip lighting is extremely efficient and needs little current because it works 'cold' – i. e. very little electrical energy is turned into waste heat as in incandescent lamps. It is roughly fifty times more effective than Edison's first carbon-filament lamps.

The mercury or sodium vapour lamps which are now used on the roads are 'discharge' lamps, invented in the early 1930's. They have a 'conductor' in the form of a gas or metallic vapour at low pressure; this is raised to incandescence by the electric current, and emits light of one characteristic colour, greenish-blue (mercury vapour) or yellow (sodium vapour). They are 'monochrome' lamps, that is, they emit light of only one colour, which makes it easier for the motorist to distinguish objects on the roads; it is also less scattered by mist or fog. True, that light makes people look like ogres – but it makes our streets definitely safer by night.

THE STEAM TURBINE

It is most important to remember that electricity is only a means of distributing energy, of carrying it from the place where it is produced to the places where it is used. It is not a 'prime mover' like the steam-engine or even the water mill. A generator is no use at all unless it is rotated by a prime mover. During the' first few years of electric power there was no other way of moving the generators than either by the force of falling water or by ordinary steam-engines.

Soon, however, there came a new and very efficient prime mover, the steam-turbine.

The steam-turbine must be a much more efficient and powerful prime mover than the reciprocating engine because it must short-cut the complicated process of converting steam energy into rotary motion via reciprocating motion. But the problems involved in building such a machine seemed formidable, especially that of high-precision engineering. It was only towards the end of the nineteenth century that engineering methods were developed highly enough for a successful attempt.

Two men undertook it almost simultaneously. The Swedish engineer, Gustaf Patrik de Laval, built his first model in 1883. He made the steam from the boiler emerge from four stationary nozzles arranged around the rim of a wheel with a great number of small inch, de Laval's turbine wheel rotated at up to 40,000 revolutions per minute. He supported the wheel on a flexible shaft so that it would adjust itself to fluctuations of pressure– which, at such speeds, would have broken a rigid shaft in no time.

De Laval geared an electric generator to his turbine after he had succeeded in reducing the speed of rotation to 3,000 r. p. m. His turbo-generator worked, but its capacity was limited, and it was found unsuitable for large-scale power stations. Although the simplest form of a machine has often proved the most efficient one in the history of technology, this was not the case with the steam-turbine. Another inventor, and another system, proved much more successful.

In 1876 Charles Parsons began to work on the idea of a steam-turbine, for which he forsaw a wide range of applications. The reciprocating steam-engine, which was unable to convert more than 12 per cent of the latent energy of coal into mechanical power, was not nearly effiuient enough for the economical generation of electricity – energy leaked out right and left from the cylinder, and the condenser. Besides, there were limits to the size in which it could be built, and therefore to the output: and Parsons saw that the time had come to build giant electric power stations.

As he studied the problem he understood that the point where most would-be turbine inventors[1] had been stumped was the excessive velocity of steam. Even steam at a comparatively low pressure escaping into the atmosphere may easily travel at speeds of more than twice the velocity of sound – and high-pressure steam may travel twice as fast again, at about 5,000 feet per second. Unless the wheel of a turbine could be made to rotate at least at half the speed of the steam acting upon its blades, there could be no efficient use of its energy. But the centrifugal force alone, to say nothing of the other forces which de Laval tried to counter with his flexible shaft, would have destroyed such an engine.

Parsons had the idea of reducing the steam pressure and speed, without reducing efficiency and economy, by causing the whole expansion of the steam to take place in stages so that only moderate velocities would have to be reached by the turbine wheels. This principle still forms the basis of all efficient steam-tirbines today. Parsons put it into practice for the first time in his model of 1884, a little turbine combined with an electric generator, both coupled without reducing gear and revolving at 18,000 r. p. m. The turbine consisted of a cylindrical rotor enclosed in a casing, with many rings of small blades fixed alternately to the casing and to the rotor. The steam entered the casing at one end and flowed parallel with the rotor ('axial flow'); in doing so it had to pass between the rings of blade – each acting virtually as a nozzle in which partial steam expansion could take place, and the jets thus formed gave up their energy in driving the rotor blades.

It was a more complicated solution of the problem than de Laval's, but it proved to be the right one. The speed of 18,000 r. p. m. used the energy of the steam very well, and the generator developed 75 amperes output at 100 volts. The little machine, built in 1884, is now at the Science Museum.

Parsons expected, and experienced, a good deal of opposition – after all, there were enormous vested interests in the manufacture of reciprocating steam-engines. He began to build some portable turbo-generators, but there were no buyers. Strangely enough, a charity event created the necessary publicity for the turbine. In the winter of 1885-1886, a pond froze over, and a local hospital decided to raise funds by getting young people to skate on the ice and charging for admission. The Chief Constable had the idea of asking Mr. Parsons to illuminate the pond with electric lamps, powered by one of the portable 4-kW turbo-generators.

The event was a great success, and the newspapers wrote about it. The next step was that the organizers of the Newcastle Exhibition of 1887 asked Parsons to supply the current for its display of electric lighting. Parsons, who died in 1931 at the age of 76, lived long enough to see one of his turbines producing more than 200,000 kW. He also suceeded in introducing his steam-turbine as a new prime mover in ship propulsion.

Until this day, the steam-turbine has held its place as the great prime mover for the generation of electricity where no water power is available. The steam which drives them in the power stations may be raised by coal, oil, natural gas, or atomic energy – but it is invariably the steam-turbine which drives the generators; Diesel-engines are the exceptions, and are only used where smaller or mobile stations are required and no fuel but heavy oil is available. Today's steam-turbines, large or small, run at much lower speeds than Parson's first model, usually at 1,000–3,000 r. p. m.

When, a quarter of a century after Charles Algernon Parsons's death, the first nuclear power station in the world started up, his steam-turbines were there to convert the heat from the reactor into mechanical energy for the generators. The atomic age cannot do without them – not yet.

THERMAL POWER-STATION

A modern thermal power-station is known to consist of four principal components, namely, coal handling and storage, boiler house, turbine house, switchgear.

If you have not seen a power-station boiler it will be difficult for you to imagine its enormous size.

Besides the principal components mentioned above there are many additional parts of the plant. The most important of them is the turbogenerator in which the current is actually generated.

A steam turbine requires boilers to provide steam. Boilers need a coal-handling plant on the one hand and an ash-disposal plant on the other. Large fans are quite necessary to provide air for the furnaces. Water for the boilers requires feed pumps. Steam must be condensed after it has passed through the turbines, and this requires large quantities of cooling water. The flue gases carry dust which must be removed by cleaning the gases before they go into the open air.

A modern thermal power-station is equipped with one or more turbine generator units which convert heat energy into electric energy. The steam to drive the turbine which, in its turn, turns the rotor or revolving part of the generator is generated in boilers heated by furnaces in which one of three fuels may be used–coal, oil and natural gas. Coal continues to be the most important and the most economical of these fuels.

Large installations with mighty turbogenerators are operating at a number of thermal power-stations in the USSR. It is necessary to point out that the power machine building industry has started to manufacture even greater capacity installations for thermal power-stations.

At present great attention is paid to combined generation of heat and electricity at heat-and-power plants and to centralized heat supply. One of the world's largest heat-and-power installations is operating at the Moskowskaya thermal power-station-25.

Thermal power-stations are considered to be the basis of the Soviet power industry. More than 80% of the country's total power output comes from the above stations.

It is necessary to say that separate power-stations in our country are integrated into power systems. Integration of power systems is a higher stage in scientific and technical development of power engineering. The Integrated Power System in the central part of the USSR is one of the largest in the world. It covers the territory from the Volga river to the Western boundaries of our country and is connected with power systems of the European socialist countries.

HYDROELECTRIC POWER-STATION

Water power was used to drive machinery long before Polzunov and James Watt harnessed steam to meet man's needs for useful power.

Modern hydroelectric power-stations use water power to turn the machines which generate electricity. The water power may be obtained from small dams in rivers or from enormous sources of water power like those to be found in the USSR. However, most of our electricity, that is about 86 per cent, still comes from steam power-stations.

In some other countries, such as Norway, Sweden, and Switzerland, more electric energy is produced from water power than from steam. They have-been developing large hydroelectric power-stations for the past forty years, or so, because they lack a sufficient fuel supply. The tendency, nowadays, even for countries that have large coal resources is to utilize their water power in order to conserve their resources of coal. As a matter of fact, almost one half of the total electric supply of the world comes from water power.

The locality of a hydroelectric power plant depends on natural conditions. The hydroelectric power plant may be located either at the dam or at a considerable distance below. That depends on the desirability of using the head supply at the dam itself or the desirability of getting a greater head.-In the latter case, water is conducted through pipes or open channels to a point farther downstream where the natural conditions make a greater head possible.

The design of machines for using water power greatly depends on the nature of the available water supply. In some cases great quantities of water can be taken from a large river with only a few feet head. In other cases, instead of a few feet, we may have a head of several thousands of feet. In general, power may be developed from water by action of its pressure, of its velocity, or by a combination of both.

A hydraulic turbine and a generator are the main equipment in a hydroelectric power-station. Hydraulic turbines are the key machines converting the energy of flowing water into mechanical energy. Such turbines have the following principal parts: a runner composed of radial blades mounted on a rotating shaft and a steel casing which houses the runner. There are two types of water turbines, namely, the reaction turbine and the impulse turbine. The reaction turbine is the one for low heads and a small flow. Modified forms of the above turbine are used for medium heads up to 500-600 ft, the shaft being horizontal for the larger heads. High heads, above 500 ft, employ the impulse type turbine. It is the reaction turbine that is most used in the USSR.

Speaking of hydraulic turbines, it is interesting to point out that in recent years there has been a great increase in size, capacity, and output of Soviet turbines.

Hydropower engineering is developing mainly by constructing high capacity stations integrated into river systems known as cascades. Such cascades are already in operation on the Dnieper, the Volga and the Angara.

NUCLEAR POWER PLANT

The heart of the nuclear power plant is the reactor which contains the nuclear fuel. The fuel usually consists of hundreds of uranium pellets placed in long thin cartridges of stainless steel. The whole fuel cell consists of hundreds of these cartridges. The fuel is situated in a reactor vessel filled with a fluid. The fuel heats the fluid and the super-hot fluid goes to a heat exchanger, i. e. steam generator, where the hot fluid converts water to steam in the heat exchanger. The fluid is highly radioactive, but it should never come into contact with the water that is converted into steam. Then this steam operates steam turbines in exactly the same way as in the coal or oil fired power-plant.

A nuclear reactor has several advantages over power-plants that use coal or natural gas. The latter produce considerable air pollution, releasing combusted gases into atmosphere, whereas a nuclear power plant gives off almost no air pollutants. As to nuclear fuel, it is far cleaner than any other fuel for operating a heat engine. Furthermore our reserves of coal, oil and gas are decreasing so nuclear fuel is to replace them. It means that coal and oil can be used for some other purposes. The amount of nuclear fuel which the nuclear power-plant consumes is negligible while the world's uranium and thorium resources will last for hundreds of years.

The construction of the world's first nuclear power-plant in Obninsk near Moscow is a great historical event and the beginning of atomic energetics. Since then our country has achieved a great progress in this field. It should be noted that while the unit capacity of the Obninsk nuclear power-plant was five thousand kW, that of the first unit of the Leningradskaya nuclear power-plant was one million kW.

Our industry produces two main types of reactors namely vessel-type reactors and channel-type reactors. The former are installed at the Novovoronezhskaya and the Armenian nuclear power-plants, the latter operating at the Leningradskaya and Kurskaya power-plants.

It is necessary to mention here that channel-type reactors have been operating since 1954 at the world's first nuclear power-plant and in the far North-East of our country where they produce both electricity and heat.

The nuclear power-stations are mostly designed for generation of electricity. If a station generates only electric energy, it is equipped with condensing turbines and the station is known as a condensing one. At present the nuclear power-stations mainly operate as condensing plants. The nuclear power-stations designed to produce not only electrical energy but also heat are called nuclear heat-and-power plants.

A fast-neutron reactor which supplies both electricity and heat for desalting sea water was put into operation in Shevchenko on the Caspain Sea. Its capacity is partly used for generating electricity, the rest going as heat to obtain desalted water. It should be also mentioned that that area has no natural fresh water and was a lifeless desert before the nuclear power plant began operating there.

According to the program of nuclear power development, the nuclear power plants are mainly built in the European part of the USSR. This increases the power supply reliability in the most industrially developed areas of our country. Besides it reduces the transportation of fuel from the East and saves millions tons of coal and oil.

In 1979, there were 226 nuclear power-plants all over the world. It is not a very great figure compared with the thermal and hydropower stations. However, by the end of the present century half of all the world's electricity will come from nuclear power plants.

Of all the methods of energy production nuclear power engineering presents the least danger to nature. But so far it is incapable of providing the necessary amount of energy–the road It has passed is too short. Therefore, along with the accelerated construction of nuclear power-stations, much attention will be paid in the USSR to the development of coal-based thermal power-stations reliably provided with fuel resources.

In keeping with the economic and social development plan of the USSR for 1981-1985 and for the period up to 1990 electricity production will reach a great figure.

REACTOR OF THE FUTURE

Man receives nine-tenths of the energy he needs by burning valuable materials like oil, coal and gas in furnaces and engines. However, the resources of these materials are not unlimited. It is estimated that they will be exhausted in 150-200 years or so. What will happen then? Shall we leave the future generations without energy? These are the questions the scientists are mostly interested in.

Soviet scientists are intensively working at the problem of creating controlled thermonuclear reactors. Positive results of research in this field would give man a practically inexhaustible source of energy.

The tests on the Tokomak-7, the world's first large thermonuclear installation with superconducting magnetic windings have proved the possibility of creating supercon-
ducting magnetic systems for retaining plasma at one million degrees Centrigrade.

The huge building in which the experiments are made looks like a big factory. The equipment and installations simulate and recreate the processes going on inside the Sun and in the remote stars. Scientists try to tame matter in a plasma state. Theoretical calculations and numerous experiments show that a controlled thermonuclear reaction would take place if we could heat a compound of 10^{14} nuclei of heavy isotopes of hydrogen deuterium and tritium to a temperature of- one hundred million degrees and make the tiny ball shine for, at least, one second.

An inexhaustible terrestrial sun would light up, its light dispelling the forecasts about the inevitable energy crisis.

This is the reactor of the future. The nearest to it, that we have at present, are the Tokomaks constructed by the Soviet scientists. The Institute of Atomic Energy named after Kurchatov where the Tokomaks were born made the next big steps forward on this difficult road. The Tokomak-7 proved in practice for the first time that the magnetic windings cooled to cosmic cold could become a superconductor even within 35 cm from the plasma heated to a million degrees.

The Tokomak-7 is about the same size as the preceding the Tokomak-10. But unlike the latter it has superconducting coils to create the magnetic field preventing the plasma from coming, into contact with the chamber walls.

What are the advantages of the new coils? It is possible to raise the plasma temperature to 13 million degrees in the Tokomak-10. But to reproduce a thermonuclear reaction lasting half a second, the installation requires the energy produced by a 200 thousand kW power plant. The superconducting coils require thousands of times less energy than the copper ones in the Tokomak-10. Let us consider another advantage of the Tokomak-7. The experiment on the Tokomak-10 lasts less than a second. Then it has to be turned off so that the coils would $_N$ not overheat, whereas the Tokomak-7 having superconducting coils can operate as long as required.

Using superconductivity in thermonuclear installations, it is possible to make experiments without thinking about the coils overheating and at much less energy consumption. This paves the way to intense research on the Tokomak-15. The latter is an intermediate step to the thermonuclear power plant. It is twice the size of the Tokomak-7. A smaller Tokomak-11 is used for experiments on methods to heat plasma to much higher temperatures by ejecting a beam of fast neutron atoms of hydrogen and deuterium into the burning area.

As for fuel the thermonuclear power plant would use sea water or a variety of hydrogen it contains in enormous amounts.

In short, our scientists do their best to carry out a controllable thermonuclear reaction so as to light up the man-made sun on earth.

NON-TRADITIONAL RENEWABLE SOURCES OF ENERGY

It is known that much is being done in the world today for the development of non-traditional sources of energy. Without them the Earth cannot support its present population of 5 billion people and probably 8 billion people in the 21st century.

Now we are using traditional powerhouses, that is, oil, natural gas, coal and water power with the consumption of more than 50 billion barrels per year. It is evident that these sources are not unlimited.

That is why it is so important to use such renewable sources of energy as the sun, wind, geothermal energy and others. Research is being carried out in these fields.

One of the most promising (перспективный) research is the development of power stations with direct transformation of solar energy into electricity on the basis of photo-effect. It was Russia that was the first in the world to develop and test a photoelectric battery of 32,000-volts and effective area of only 0.5 sq.m., which made it possible to concentrate solar radiation. This idea is now being intensively developed in many countries.

However, the efficiency of a solar power station is considerably reduced because of the limited time of its work during the year. But it is possible to improve the efficiency of solar power stations by developing different combinations of solar power stations and traditional ones – thermal, atomic and hydraulic. Today some engineers are working at the problem of developing electric power stations with the use of a thermal-chemical cycle. It will operate on products of the transformation of solar energy, whereas me «solar» chemical reactor uses CO2 and water steam of the thermal power station. The result is that we have a closed cycle.

In Kamchatka there are geothermal, power stations operating on hot water-steam mixture from the depths of about a kilometre. In some projects water will be heated by the warmth of mountains at a depth of four-five km.

It is planned that plants working on the energy of the solar heat provided by the sun will be built on a larger scale.

That different wind energy plants are being developed is also well-known. These energy plants can be small (of several kilowatts) and large powerful systems.

It is important that all these advances in developing new sources of energy and improving the old ones help to solve the energy problem as a whole and they do not have negative effects on the environment.

NEW HOPE FOR ENERGY

Recently some ceramic materials have been found to be superconductors. Superconducting ceramics are substances which can transmit electric currents with no loss of energy at temperatures much higher than conventional superconductors (that is, at the temperature of liquid nitrogen).

One use for the new superconductors would be to replace those that need the extreme cold of liquid helium – huge superconducting electromagnets used in nuclear magnetic resonance research, atomic particle acceleration and research reactors.

Other types of electromagnets made with superconductors could be used to lower the cost of electric generation and storage. Such uses may take 10 years of research, a quicker use will probably be in electronics.

Researchers now estimate that tiny but immensely powerful highspeed computers using superconductors may be three to five years away. Further off are 300 m.p.h. trains that float on magnetic cushions which now exist as prototypes but may take at least a decade to perfect. Power lines that can meet a city's electric needs with superconductor cables may be even further in the future.

Meanwhile, scientists around the world are trying to turn the new materials into useful products. Among the most notable is a micron-thin film to transmit useful amounts of electric current without losing superconductivity. The film could be used in the microscopic circuitry of advanced computers as high-speed pathway (маршрут, соединение) between computer chips.

Several nations are known to be very active in superconductor research. For example, the United States is spending millions of dollars on such research, much of it for military uses: projectile accelerators, lasers, ship and submarine propulsion.

SAVE THE PLANET

Today's global economy has been formed by market, not by the principles of ecology. This has created an economy that is destroying its natural support system (система естественной поддержки). It is eco-economy that we need today to save the planet. An eco-economy is one that satisfies our needs without affecting the prospects of future generations to meet their needs. Therefore, it is necessary to turn our economy into in eco-economy. To build an eco-economy means to restore carbon balance, to stabilize population and water use, and to conserve forests, soils and variety of plant and animal life in the world.

Such an eco-economy will affect every side of our lives. It will change how we light our homes, what we eat, where we live, how we use our free time, and how many children we have. It will give us a world where we are a part of nature.

Building a new economy means eliminating and replacing old industries, restructuring existing ones, and creating new ones. The generation of electricity from wind is one such industry. Soon millions of turbines will be turning wind into electricity. In many countries, wind will provide both electricity and hydrogen. Together, electricity and hydrogen can meet all the energy needs of a modern society.

Another industry that will play an important part in the new economy is management of available water supply most efficiently. Irrigation technology will become more efficient. The recycling of urban waste water will become common. At present, water flows into and out of cities, carrying waste with it. In the future, water will be used again and again, never discharged (спускать, выливать). As water does not lose its quality from use, there is no limit to how long it can be used, as long as (пока) it is cleaned before reuse.

One can easily see eco-economy changes in some countries. It is known that Denmark is the eco-economy leader. It has stabilised its population, banned (запрещать) the construction of coal power plants, banned the use of non-refillable drink containers, and is now getting 15 per cent of its electricity from wind. Besides, it has restructured its urban transport networks; now 32 per cent of all trips in Copenhagen are on bicycles. Denmark is still not close (near) to balancing carbon emission, but it is moving in that direction.

English-Russian phrases on electricity

ability	способность
achievement	достижение
add v	прибавлять, присоединять
adjust	регулировать; устанавливать
advertise v	рекламировать
air	воздух
all other circumstances being equal	при прочих равных условиях
all over the world	во всем мире
alternately	поочередно
alternating current	переменный ток
amount	количество
amount to	доходить до
an odd succession of scientists	ряд ученых, не связанных между собой
animal tissue	живая ткань
appliance	прибор
application	применение
approach	подход
armature	якорь
around A. D. 1500	около 1500 г. н. э.
around the turn of the century	на грани двух веков
as a matter of fact	действительно, на самом деле
as for	что касается
as soon as	как только
as well	также
as well as	так же как
at a result	в результате

at least	по крайней мере
at once	сразу, немедленно
at present	в настоящее время
at rest	в покое
at right angles	под прямым углом
at the throwing of a switch	при включении рубильника
at will	по желанию
attract v	привлекать, притягивать
bare wire	оголенный провод
battery	батарея
because it works 'cold'	потому что она не нагревается во время работы
because of	из-за, вследствие
before long	очень скоро
behave v	вести себя, работать
below adv	ниже, внизу
belts and pulleys	ремни и блоки
benefit n	выгода, польза
body	тело
boil v	кипеть
boiling point	точка кипения
bonding sites	свободные связи
broad a	широкий
brush	щетка
bucket-shaped blades	ковшеобразные лопасти
burn	сжигать
but so far ahead of his time	но он настолько опередил свое время
by overhead cables	по воздушному кабелю
by-products	побочные продукты

cable	кабель
calculate	рассчитывать, вычислять
capacity	мощность; способность; емкость
carry	нести; пропускать (ток)
carry out	проводить
cause	вызывать, заставлять; причинять
cell	элемент
certain	некоторый; определенный
change	изменять, преобразовывать
channel	канал
charge	заряд
chemical	химический
chemistry	химия
closed circuit	замкнутая цепь
coal	уголь
coil	катушка
coil of pipes	змеевик
cold-jet injection	вспрыскивание струи холодной воды
collision	столкновение
come into contact	соприкасаться
commutator	коллектор
compared with	по сравнению с
complete	замкнутый; полный
compression	сжатие
condition	условие; состояние
conduct	проводить
connect	соединять, связывать
consider	рассматривать; считать
considerable	значительный

consist of	состоять из
constant	постоянный
construct	строить, создавать
consumer	потребитель
contain	содержать
continue v	продолжать
contribution	вклад
control	управлять, контролировать
conventional	обычный, общепринятый
convert	превращать, преобразовывать
cool v	охлаждать
copper	медь
cord	шнур
core	сердечник
cotton gin	хлопкоочистительная машина, волокноотделитель
covalently bonded carbon atoms	ковалентно связанные атомы углерода
cover	покрывать
credit for its discovery is given	честь его открытия принадлежит
current n	электрический ток
damage	разрушать, повреждать
dangerous	опасный
data	данные
dead centre	мертвая точка
deal with	иметь дело; рассматривать
decisive 'break-through'	решающий момент
decrease	уменьшить, понижать
degree	градус; степень
deliver v	доставлять

desirable	желательный
destroy	разрушать
detect	обнаруживать, открывать
determine	определять
develop	развивать, разрабатывать
develop heat	выделять тепло
development	развитие
device	прибор, приспособление
diehards	консерваторы
difference	разность, разница
direct current	постоянный ток
direction	направление
discharge	разряжать
discover v	открывать, обнаруживать
distribution	распределение
do not appear out of the blue	-г- не (ср. с русск.: "как гром среди ясного неба")
do without	обходиться без чего-либо
drive	приводить в движение
due to	благодаря, вследствие, из-за
effect	действие, влияние; результат
efficiency	эффективность; коэффициент полезного действия
electric(al)	электрический
electrical engineering	электротехника
electrify	электрифицировать; электризовать
electromotive force	электродвижущая сила
emit	излучать, выделять, испускать
employ	использовать, применять

engineer	инженер
engineering	техника
enterprise n	предприятие
equipment	оборудование
establish v	учреждать, организовывать
excess	избыток, излишек
exist	существовать
expansion	расширение, увеличение
expect	ожидать; рассчитывать
expensive	дорогой
experience	испытывать; претерпевать
explain	объяснять
explore v	исследовать, изучать
facility n	сооружение, оборудование
famous	известный
far apart	на расстоянии
fault	повреждение, авария
'feed-back' devices	приборы с обратной связью
field	поле; область (науки, техники)
field winding	обмотка возбуждения
finally adv	наконец
find out	выяснять; понимать
fire	огонь; пожар
first application of mass production methods	первое применение методов промышленного (массового) производства
fit v	соединять, подгонять
flow	течь
flux	поток
follow v	следовать (за)

force	сила
free	свободный
freezing point	точка замерзания
friction	трение
fulfil	выполнять
furnace	печь, горн
fuse	предохранитель
gas-blast system	система, основанная на взрыве газа
gear wheels	зубчатые колеса
Geiger, counter	счетчик Гейгера, является одним из основных приборов в ядерной физике
generally	обычно
generally speaking	вообще говоря
generate	производить, вырабатывать, генерировать
generator	генератор
glass	стекло; стакан
great deal	значительно
growth	рост, увеличение
harness	использовать энергию (воды, ветра, солнца)
heat	тепло, теплота
hence adv	следовательно
high-precision engineering	устройства высокой точности
his famous kite-and-key experiment	свой знаменитый опыт с воздушным змеем и ключом
implementation n	выполнение, осуществление
in addition to	вдобавок, в дополнение
in case	в случае
in certain respects	в некотором отношении

in motion	в движении
in no time at all	мгновенно
in one's turn	в свою очередь
in question	обсуждаемый, о котором идет речь
in spite of	несмотря на
in the form	в виде
increase	возрастать; увеличивать
indicate	показывать, указывать
induction coil	индукционная катушка
induction motors	индукционные моторы
influence	влиять
inject	вводить, впрыскивать
input	вход; подводимая мощность; входной
install	устанавливать, монтировать
instead of	вместо
insulation	изоляция
interact	взаимодействовать
into the national grid	в национальную энергетическую систему
introduce v	вводить
invent	изобретать
investigation n	исследование
ionize	ионизировать
iron	железо
kind	вид, род
knowledge	знания
laboratory	лаборатория
lack v	нуждаться
last v	сохраняться, длиться
launch v	запускать

law	закон, право
leak off	утекать
light	свет; светлый
like	подобный, похожий, как
likely adv	вероятно
liquid	жидкость
load	нагрузка. - .
local hospital decided to raise funds	местная больница решила извлечь выгоду
lose v	терять
machinery	машины, механизмы
magnetism	магнетизм
maintain v	обслуживать, содержать
make reference to	ссылаться на, упоминать
make up	состоять
make use of	использовать
master v	овладевать
matter	вещество, материя
mean	значить, означать
means	средство
measure	измерять
meet requirements	удовлетворять требованиям
mention	упоминать
mercury	ртуть
mighty	мощный, могущественный
missing bonding electron	дефектный электрон
mission n	задача, полет
more or less	более или менее
moreover adv	более того

most would-be turbine inventors	большинство мечтавших изобрести турбину
motion	движение
movement	движение
name after	называть в честь
natural	естественный
needle	стрелка
needless to say	нечего и говорить
negative	отрицательный
negligible	незначительный, пренебрежимо малый
nevertheless	тем не менее
no longer	больше не
note v	отмечать
now and then	время от времени
nozzle	сопло
nuclear	ядерный, атомный
number	число; номер
numerous	многочисленный
observation	наблюдение
obtain	получать
of getting rid of it	освободиться от них
offer resistance	оказывать сопротивление
on the basis of	на основе
on the one hand	с одной стороны
on the other hand	с другой стороны
on the spur of the moment	экспромтом
open circuit	разомкнутая цепь
operate	работать, действовать
opportunity n	благоприятная возможность

opposite	противоположный
output	выходная мощность; выходной
overheat	перегревать
particle	частица
pass v	пропускать
path	путь; контур электрической цепи
peaceful	мирный
per capita	на человека; на душу населения
perform	выполнять, совершать
phenomenon	явление
physics	физика
place	помещать, класть
play a part	играть роль
point out	указывать
pole	полюс; столб, опора
positive	положительный
possess	обладать
potential difference	разность потенциалов
power	энергия; держава
predict v	предсказывать
present v	представлять
pressure	давление
previously adv	ранее, предварительно
primary	первичный; первичная обмотка трансформатора
principal	основной, главный
produce	производить, создавать, выпускать
prominent a	выдающийся, известный
promote v	способствовать, содействовать

properly adv	должным образом, правильно
property	свойство
protect	защищать
prove	доказывать
provide	снабжать, обеспечивать
purpose	цель, намерение
put into operation	вводить в действие
put into use	вводить в действие, запускать
quantity	количество
random a	беспорядочный, случайный
range	диапазон
rare earths	редкоземельные металлы
rate	скорость
rated capacity	номинальная мощность
reach	достигать
reason	причина, основание
reciprocating movement	возвратно-поступательное движение
reduce	понижать, уменьшать
relation	связь; отношение
reliable	надежный
remember	помнить, вспоминать
remove	удалять, устранять
repel	отталкивать
replace	заменять
represent	представлять
require	требовать
research	исследование
resist	сопротивляться, противодействовать
resistivity n	удельное сопротивление

result in	приводить к; заканчиваться
return v	возвращаться
reverse	изменять на обратное, реверсировать
revolutions per minute	оборотов в минуту
rise	подниматься, возрастать
rotate	вращать(ся)
rubber	резина
rule	правило
safety device	предохранительное устройство
satisfactory a	приемлемый, удовлетворительный
scale	масштаб; шкала
scientific	научный
secondary	вторичный, вторичная обмотка трансформатора
semiconductor	полупроводник
serve	служить, обслуживать
short circuit	короткое замыкание
shunt	шунт; шунтовой
similar	одинаковый, похожий, однородный
single	один
size	размер
socket	розетка, патрон (электролампы)
solar	солнечный
solve a problem	решать задачу, проблему
source	источник
source of supply	источник питания
speed	скорость
squirrel-cage motor	мотор типа беличьего колеса
stable elements	устойчивые элементы

statement	утверждение; формулировка
stationary	неподвижный, стационарный
stay v	оставаться, жить
steam power plant	тепловая электростанция
steel	сталь
step down	понижать
step up	повышать
stepping stone	как первый шаг, как трамплин
straight	прямой
stroke of luck	большая удача
subject	предмет; тема
substance	вещество; материя
successfully	успешно
suddenly adv	вдруг, внезапно
sufficiently adv	достаточно
supply v	снабжать, обеспечивать
suspend	подвешивать
switch	выключатель
take place	происходить, иметь место
take time	занимать время
tend v	стремиться, иметь тенденцию
tension	напряжение
term	термин
terminal	зажим, вывод, клемма
that is to say	то есть, иными словами
the former	первый из упомянутых
the latter	последний из упомянутых
the rest of	остаток; остальной
theory	теория

thermionic converter	термоионный преобразователь
time and labour saving appliances	электроприборы, экономящие время и труд
torque	момент, пусковой момент
transform	преобразовывать
transmit	передавать (электроэнергию); посылать
travel	путешествовать
trouble n	неисправность, повреждение
truly	поистине
try	пытаться; испытывать
turn	виток
turn off	выключать
turn on	включать
twitching effect	эффект сокращения мышц
under consideration	рассматриваемый, обсуждаемый
unit	единица; установка, агрегат
unless	если не
unlike	разноименный
valuable	ценный
value	величина
variety	разнообразие
various	различный
velocity	скорость
vessel	котел реактора
voltage	напряжение
Voltaic pile	гальваническая батарея
waste	потеря, пустая трата
watch television	смотреть телевизор
waterfall	водопад

wave	волна
weight	вес
well above	намного выше
white-hot	раскаленный добела
whole	целый, весь
willy-nilly	волей-неволей
winding	обмотка
wire n	провод
withstand	выдерживать

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