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Nuclear Physics*

By

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I

INTRODUCTION

The field of nuclear physics is so vast that it can form the subject matter not of three lectures but fifty lectures extending over a period of a full year. Therefore, in these three lectures I can only touch upon certain limited aspects of the subject of nuclear physics. In the first lecture which is more of a general character, I shall give a brief resume of the progress of nuclear physics during past sixty years and refer to the important discoveries which gave us a clear picture of the structure of the nucleus and also to the different stages in the discovery of nuclear fission and release of atomic energy. The second lecture will be devoted to a brief description of the methods of detection of nuclear particles. In the third lecture, I shall give a brief resume of the various types of nuclear machines that have been constructed and are in use for effecting nuclear transformations.

PROGRESS OF NUCLEAR PHYSICS

If a piece of an element, let us say a piece of iron, is divided into small parts and this division continued, one finally arrives at small indivisible units which are the atoms of modern chemistry. If the same process is repeated with a chemical compound, we finally arrive at the smallest unit

* The substance of a course of three lectures delivered on February 25th, 26th, and 27th, 1955, under the auspices of the Annamalai University.

which still has the properties of the compound which is called a molecule. All molecules of any substance contain a definite number of atoms of various kinds. It was soon established that each chemical element has a definite weight—called the atomic weight. Hydrogen has the smallest atomic weight 1 and Uranium has the heaviest namely 238. In chemical reactions molecules change their composition, but the atoms always remain the same. Chemistry stated that it was not possible to achieve the alchemists' dream, namely to change cheap metals like iron or lead into gold.

When the atomic weights were accurately known, two remarkable discoveries were made. The first of these was the periodic system of elements discovered by Mendeleeff. He found that if you arranged the elements according to increasing atomic weight, then their chemical properties repeat periodically. The second fact was that most atomic weights turned out to be near integers. This rule was more accurately followed when the atomic weight of oxygen was taken as 16. There were some notable exceptions to this rule such as chlorine which had an atomic weight of 35.5. Towards the end of the 19th century, it was possible to determine the number of atoms in a *given* mass of material. The gram molecular weight of any element contains 6×10^{23} atoms. The size of an individual atom is exceedingly small. About one hundred million atoms laid side by side are an inch long.

The first sign of the divisibility of the atom came at the end of the 19th century (1897) when Sir J. J. Thomson described how small electric particles could under certain conditions come out of atoms. These small particles he called "electrons". He carried out a series of pioneering experiments and showed that the particles were all found to be alike in charge as well as in weight. The charge of the electron is negative and is the smallest electrical charge that has ever been observed. It is therefore used in physics as the unit of charge. The weight of an electron is much smaller than that of the lightest atom about 1840 electrons weigh as much as one hydrogen atom.

Another important discovery was made almost at the same time. This is the discovery by Becquerel of a phenomenon called natural radio-activity. Certain heavy elements like uranium and thorium continuously and spontaneously emitted strange radiations. The process was called radio-activity. They emitted particles which carried two positive charges and could be shown to be identical with the ionised helium atom. These particles were called "alpha" particles. Other radiations also came out of the radio-active nuclei, so-called beta rays. These were ordinary electrons carrying one negative charge with practically no mass. There were also radiations of the type of electro-magnetic waves, of the same form as X-rays. They were called gamma rays. There are two characteristic properties of these radio-active elements. They are (1) that the process of radio-activity was found to be a spontaneous one without any external influence and independent of such influence. (2) If one isolates one atom, one cannot tell as to when this particular atom will break up and emit these radiations. On an average, extending over a period of time one can estimate that certain percentage of atoms would have disintegrated. The characteristic property of any radio-active element is therefore the half life *i. e.*, the period by which half the number of atoms in a given quantity would have disintegrated. The discovery of radioactivity showed for the first time that the atoms, for the time being, of a very few heavy elements were capable of being broken up. It was also established that in the breaking up of each such atom, energy which was a million times greater than that involved in a chemical reaction such as combination of an atom of carbon with oxygen (burning) was released. This energy is taken by the out-going α , or β or γ radiation. But this was only of academic interest as the release of energy could not be influenced in any way. The energy of nuclear particles is expressed in electron volts, ev. One electron volt energy corresponds to that acquired by a particle of unit charge falling through a potential difference of one volt, $1 \text{ ev.} = 1.6 \times 10^{-12} \text{ ergs}$, $1 \text{ Mev} = 1.6 \times 10^{-6} \text{ ergs}$.

The study of radio-active elements produced in the process of natural radio-active disintegrations gave support to the suggestion that

the atoms of an element need not be identical in mass. Several groups of elements (*e. g.* lead) having identical properties but different atomic weights were formed in this process by radio-active disintegration. This means that elements 'within any one group must occupy the same place in the periodic table of the elements. Soddy suggested the name "Isotopes" for such elements. Search for isotopes of non-radio-active elements was begun by J. J. Thomson in 1910. The isotopes in Neon were first established. These were extended by many others and especially by Aston who developed an instrument called mass spectrometer for detecting isotopes. We now know that all the elements with the exception of a few have stable isotopes. Cadmium has the maximum number and gold has only one isotope.

Systematic investigations on radio-activity were carried out by Rutherford and his collaborators. In 1911 Rutherford proposed a nuclear theory for the structure of atoms. He was led to this theory by the results of an experiment of Geiger and Marsden on the scattering of alpha-particles by matter. In the case of heavy elements like gold large angle scattering was observed. In order to explain this, Rutherford assumed that the entire positive charge of the atom was concentrated in a very small core called the nucleus and that the electrons occupied the space outside the nucleus. The atom is therefore supposed to consist of a very small nucleus with a net positive charge and nearly the whole mass of the atom, surrounded by a sufficient number of electrons, so that the normal atom is electrically neutral. The results of these experiments led to the conclusion that the charge of the nucleus of an atom can be represented by Z times the unit of charge e , i. e. the charge of a single electron. Z is an integer. There are only Z electrons outside the nucleus of any neutral atom. Z is called the atomic number of the element. The two characteristic properties of the nucleus of any atom are therefore the charge Ze and the mass, A . The isotopes of the same element have the same charge, but different masses. The chemical properties of any element must therefore be ascribed to the arrangement and action of the electrons outside the nucleus. Nuclear charge increases from element to element, smallest being for hydrogen (1) and largest for uranium (92).

Nuclei are made up of particles of unit atomic weight. The size of the nucleus is of the order of 10^{-13} cm. i. e., about one 20,000 th the size of an atom. Therefore the atom consists mostly of empty space, and if you could fly through the atoms, you would only occasionally meet either an electron or a nucleus.

In 1913, Prof. Niels Bohr (a Danish Physicist) developed a complete theory of the structure of the atom on the basis of Rutherford's ideas and of the quantum theory. According to him, the atom consists of a central core called the nucleus which is heavy and positively charged and is surrounded by an appropriate number of electrons. These electrons travel round the nucleus on fixed orbits, in the same way as the planets move round the sun. Emission or absorption of light takes place when an electron falls from one orbit to another.

The atom of Rutherford and Bohr is divisible and has a structure. However, it was believed that the nucleus of the atom might still have been indivisible. That this belief was not true became evident when one tried to explain the observed natural radio activity of heavy elements. A completely new perspective was opened in 1919 when Lord Rutherford used alpha particles to bombard the nuclei of nitrogen. He found that occasionally a completely new particle resulted from such a collision which turned out to be a hydrogen nucleus, a so-called proton. The nitrogen nucleus itself was transformed in this process into a nucleus of oxygen.



This discovery was of profound importance. It was now possible to change one chemical element into another by bombarding its nucleus. Thus, not only the atom but even the nucleus had been shown to be divisible and to contain yet smaller particles.

These experiments furnished us a preliminary idea of the structure of the nucleus. It was considered to be made up of protons (Hydrogen nucleus

being the unit of +ve charge), and electrons. The number of protons is determined by the atomic weight A and the number of electrons is determined to give a resultant charge +ve equal to Ze . We now know both from theoretical and experimental stand-points that this picture is not quite correct.

But the fundamental idea that every nucleus consists of a group of elementary particles is still true and this gave the clue for explaining the process of artificial disintegration of nuclei. It can be pictured as a collection of billiard balls and in order to remove one of them it is better to bombard them with a similar ball having some velocity. The alpha particles are the bombarding particles for the nuclei.

Extensive experiments on artificial transmutation of the light elements were carried out in the early thirties using the α -particles from natural radio-active sources. There were very serious limitations. Firstly, in all nuclear processes the probability of transmutation is very small *i. e.* one in 10^5 or 10^6 . Sources are very weak and not sufficiently energetic to produce transmutations in heavy elements. Therefore, there arose the necessity for producing energetic, charged particles such as protons and alpha particles artificially.

Every nucleus, since it is positively charged, is surrounded by a potential barrier. This prevents easy entry of charged particles into the nucleus. The energy required for a particle to enter any nucleus should be equal to or less than the energy of the bombarding particle on classical theory. On the basis of wave-mechanics, Gamow worked out a theory of penetration of charged particles or projectiles into the atomic nucleus. According to Gamow's theory, even if the energy of the bombarding particles is less than the energy of the potential barrier surrounding a nucleus, there is a finite probability of penetration of the particles inside the barrier and producing transformations inside the nucleus. The greater the energy of the bombarding particles the greater is the probability of penetration. This theory, therefore, gave an impetus for the development

of nuclear machines for producing artificially accelerated particles. Cockcroft and Walton in England, Van de Graaff, Lauritsen, Crane and Lawrence in America were some of the first few people who started work and succeeded in the development of nuclear machines of one type or other. Among them, Cockcroft and Walton developed a Cascade high voltage generator and using the same in conjunction with an accelerating column, they successfully produced artificial disintegration of lithium nucleus with high energy protons. Other nuclear machines such as cyclotrons and Van de Graaff Generators were constructed and used for nuclear disintegrations. Although much progress has already been made, work is still being continued in the construction of machines for producing particles of higher and higher energy. The biggest one so far constructed is capable of giving particles of energy 3.5 Bev.

While carrying out experiments on artificial transmutations, Chadwick discovered in 1932 still another type of elementary particle coming out of light nuclei when bombarded by alpha particles. These new particles had no electric charge; they were electrically neutral and were therefore called "neutrons". They had very nearly the same weight as protons, the nuclei of hydrogen. It is known that neutrons result from numerous other nuclear reactions also, but the beryllium - alpha ray reaction is still one of the most effective of the known methods of producing them. The modern source of very intense neutrons is the atomic pile to which reference will be made later in the lecture.

It is now a well-established fact that the fundamental particles of an atomic nucleus are neutrons and protons. The number of units of charge in the nucleus is equal to the number of protons contained in the nucleus. The atomic weight is approximately equal to the sum of the numbers of neutrons and protons. All the isotopes have the same number of protons in the nucleus, but the number of neutrons is different for different isotopes. Hydrogen has two isotopes of atomic weights 1 and 2, the former is the ordinary hydrogen, while the latter is called heavy hydrogen or deuterium. The nucleus of deuterium called deuteron (neutron + proton) is found to be very effective in

producing transmutations in other nuclei. The structure or composition of a few nuclei of elements is indicated below.

$${}^1_1\text{H} = 1 {}^1_1\text{H}$$

$${}^2_1\text{D} = {}^1_1\text{H} + 1 {}^1_0\text{n}$$

$${}^3_2\text{He} = 2 {}^1_1\text{H} + 1 {}^1_0\text{n}$$

$${}^4_2\text{He} = 2 {}^1_1\text{H} + 2 {}^1_0\text{n}$$

$${}^{12}_6\text{C} = 6 {}^1_1\text{H} + 6 {}^1_0\text{n}$$

$${}^{13}_6\text{C} = 6 {}^1_1\text{H} + 7 {}^1_0\text{n}$$

$${}^{16}_8\text{C} = 8 {}^1_1\text{H} + 8 {}^1_0\text{n}$$

$${}^{17}_8\text{C} = 8 {}^1_1\text{H} + 9 {}^1_0\text{n}$$

$${}^{238}_{92}\text{U} = 92 {}^1_1\text{H} + 146 {}^1_0\text{n}$$

$${}^{235}_{92}\text{U} = 92 {}^1_1\text{H} + 143 {}^1_0\text{n}$$

These neutrons and protons are held together in the nucleus by the strongest forces known. The forces are about a million times stronger than the electric forces that hold the electrons in the atom. These forces are stronger than the chemical forces which hold together the atoms in the molecule. The chemical forces are again many times stronger than the elastic forces which hold together a piece of steel, and everybody knows how difficult it is to tear apart a piece of steel. The method of measuring nuclear forces is based on Einstein's theory of the equivalence of mass and energy (1905). $E = mc^2$. One gram of mass is equivalent to an enormous amount of energy, namely about 25 million kilowatt hours. The application of Einstein's theory to nuclei is connected with the fact that the atomic weights are not exactly equal to but less than weights of the protons and neutrons of which the nuclei are made. The difference in the atomic weight between the nucleus and the separate protons and neutrons is a measure of

the great strength of the nuclear forces or binding. Very little is yet known about the nuclear forces. One of the most important and interesting problems of physics which is engaging the attention of many nuclear physicists the world over is the nature of the nuclear forces.

Energy is set free when protons and neutrons are brought together to form more complex nuclei. Two protons and 2 neutrons are combined to form a nucleus of helium, a process which is connected with great release of energy. This is the principle by which stars are supposed to generate their energy. In the case of heavier nuclei, (U, Ra) they have a greater weight than some fragments into which they might be broken up. This explains the existence of natural radio-activity in such elements.

Since Rutherford's first experiment on the transmutation of nitrogen nuclei, several hundred such nuclear transformations have been observed. They are similar to chemical reactions, with the nuclei playing the part of the atoms. The nuclei change their nature in nuclear reactions but the total number of neutrons and the total number of protons remain the same. The various projectiles used are always light nuclei, such as the nucleus of hydrogen (proton), of deuterium (deuteron), of helium (alpha particles) and the neutron. The neutron has been especially successful as a projectile to induce nuclear transformations. This is because it has no electric charge and can therefore approach the atomic nuclei without overcoming any repulsive forces. For this reason, neutrons do not need to have high energy; in fact very slow neutrons are often more effective than fast ones. The Italian Physicist, Fermi, and his collaborators have been most prominent in investigating the nuclear reactions which can be produced by neutrons. Only there is one difficulty i. e., neutrons have to be produced in nuclear reactions and as such the number that could be got was strictly limited. There is another difference between neutrons and charged particles i.e., charged particles knock electrons out of atoms and lose energy quickly when passing through matter. Neutrons, on the other hand, cannot be deflected and cannot eject electrons from atoms. The only process that happens to them is direct collision with nuclei. Because of the small size of the latter, the neutrons travel long distances before collision.

It was known for a long time that highly penetrating radiations are continuously falling on the earth from the outer space. These are called Cosmic Rays. The cloud chamber photographs taken by Anderson and Neddermeyer in August 1932 revealed the existence of a free positive electron or positron. Positrons are almost similar to electrons regarding the quantity of charge and mass. They are produced by the impact of rays on the nucleus of the atom. Blackett and Occhialini also confirmed this discovery.

Numerous types of nuclear reactions have been established. The same projectile bombarding on the same nucleus can give rise to more than one type of reaction depending upon the conditions of bombardment. A particularly interesting result of the study of nuclear transformations was the production of new radio-active nuclei known as artificially radio-active nuclei, first discovered by the French Physicist couple Joliot and Madame Curie in 1934. It has now been demonstrated that every known element may have one or more radio-active isotopes. Various means are effective in the production of such radio-active isotopes as well as of many new stable isotopes. It is often possible to produce the same isotope in several ways. Even the elements which have no stable isotope at all (elements with atomic numbers 43, 61, 85 and 87) possess radio-active isotopes which have been produced and investigated. The unit of radio-activity is the "*Curie*". The *Curie* refers to the amount of radon in equilibrium with 1 gr. of radium element. A source which decays such that 3.7×10^{10} atoms change per second is of 1—*millicurie* strength. *Rutherford* is the term used for a source which decays at the rate of 10^6 atoms per second.

Only the very heavy naturally radio-active elements emit alpha rays. For the artificially produced radio active elements the disintegration products are either electrons or positrons, the nature of the emission in any particular case being determined by the direction in which the change in nuclear charge should occur in order to arrive at a stable isotope. For example nitrogen possesses 4 isotopes with masses 13, 14, 15 and 16. Of these the lightest and heaviest are radio active. Isotope 13 emits a positron and thereby becomes a stable isotope of carbon, while the isotope 16

becomes a stable isotope of oxygen, by emitting an electron. This is fairly typical of the lighter elements. More recently it has been discovered that an unstable nucleus may depart from the usual procedure of emitting a positron, but capture a K electron (from the outer shell) instead. Evidence for this is given by the emission of the K - X-rays of the stable isotope which results from this process. In the radioactive beta transformation, a proton in the nucleus transforms itself into a neutron with the positive charge going away in the form of a positron, or a neutron may transform itself into a proton, one unit of negative charge being emitted in the form of an ordinary electron. This is a kind of exchange process and in order to make the exchange process have some physical significance, Yukawa in 1935 postulated the existence of a particle of mass intermediate between a proton and an electron. This would account for the nature of nuclear binding. This particle is called a meson. Mesons were since discovered to be components of cosmic radiation. Gardner and Lattes showed in 1948 that one form of meson could be produced in the laboratory by bombarding nuclei with very high energy alpha particles.

All nuclear reactions investigated until 1938 had one thing in common, not only was the particle initiating the reaction small, having atomic weight equal to or less than 4, but also *one of the particles resulting from the reaction was always small again having an atomic weight of 4 or less.* Besides, the quantities of new substances (both radioactive and stable) produced by the nuclear reactions, were extremely small and beyond the limits of weighable amounts. They were estimated only from their radiations and by their peculiar chemical properties. Seaborg developed an ingenious method of separating the new radio-active elements formed during nuclear transformations. The method consists in the addition of a small quantity of inactive carrier to the mixture and making the chemical separation in the usual way. The few atoms of the radio-active elements come out along with the corresponding inactive carrier.

Soon after the discovery of the neutron, Fermi and his collaborators investigated the bombardment of the heavy elements like uranium with neutrons. They reported the formation in this process of elements with

atomic numbers greater than 92 by neutron capture. Such elements were called *transuranic elements*. These so called transuranic elements showed a peculiar behaviour. Early in 1939 Hahn and Strassman in Germany discovered traces of barium in uranium bombarded with neutrons and Meitner and Frisch hit upon the correct explanation. This barium represented fragments of uranium nuclei which had split apart into two nearly equal parts spontaneously upon capture of neutrons. Experimental proof was immediately given by Joliot, Halban and Kowarski. This process of nuclear splitting is called *nuclear fission*. Soon afterwards, it was shown that thorium and protactinium as well as both isotopes of uranium, 235 and 238, may undergo this process of nuclear splitting. Niels Bohr gave the following physical picture for the process of fission. A big nucleus rather closely resembles a drop of very dense liquid and the energy released by the captured neutron may be considered to set this droplet nucleus into vibrations which are violent enough to break it up.

As soon as this phenomenon, nuclear fission, was discovered, physicists were able to calculate the energy released during this process by means of the well known Einstein's equation $E=mc^2$. The nucleus of uranium is about 0.1% heavier than that of the sum of the two fragments into which it can break up and this corresponds to very great energy (330 Mev.) The actual energy released is of the order of 200 Mev. per atom, for each uranium atom or 22,000 kilowatt—hours per gram of uranium, *i.e.*, about two hundred million times greater than that released by burning a gram of coal.

The discovery of nuclear fission alone is quite useless from the practical point of view especially if it occurs only as infrequently as many other nuclear reactions. But this is not so. Fermi and Szilard showed that in the process of fission of the uranium nucleus, secondary neutrons are emitted. If these new neutrons can in turn cause fission of other nuclei, then a nuclear chain reaction may be possible. To maintain this reaction, an average of at least one of the neutrons produced in each fission must be able to effect another fission. If the average is just one, the reaction will

proceed at a steady state, and a steady release of power will result. This is what is achieved in a Pile, a device, suggested by Fermi. If the average falls below one, the reaction will die out; if it is much greater than one, it may go with explosive violence.

The discovery of the emission of secondary neutrons is mainly responsible for the development of the chain reaction and release of power. If all the secondary neutrons are released simultaneously with fission, it would not have been possible to construct a workable pile or nuclear reactor. Actually, some of the neutrons are emitted after some definite period has elapsed after fission. These are called delayed neutrons. The emission of delayed neutrons is mainly responsible for enabling us to control the energy release in a pile or reactor. Uranium contain two isotopes with mass numbers 235 and 238. It is found that the rarer isotope of uranium, namely U^{235} is a more effective nuclear fuel than U^{238} .

As already indicated in a device called a pile first suggested by Fermi which consists of uranium imbedded in a moderator like graphite or heavy water, the fission of uranium is allowed to take place at a controlled rate. This acts not only as a source of thermal power, but a very exceptional source of neutrons, very large compared to what could be got from the ordinary atom machines. The pile is therefore used for the production of the atomic fuel Pu 239 which is a transuranic element and is formed as a result of the capture of neutron by U^{238} , and also a large variety of radioactive isotopes of elements in weighable quantities. This has led to a new field of research called Tracer Elements.

The state of world history at the time of the discovery of nuclear fission made it inevitable that nuclear energy should have its first practical utilisation in a super-bomb. It might be recalled that chemical energy also saw its first utilization in explosives. To produce an "atom bomb" it is necessary only to bring together a sufficiently large mass of fairly pure atomic fuel as U 235 or Pu 239. There are enough stray neutrons in air to touch it off. If the mass is large enough to insure an average of more than one useful neutron for each fission produced, the reaction will proceed

with explosive violence. This is not a military secret, but an actual fact. But the actual means for accomplishing this is another matter.

It should be mentioned that in the formation of a nucleus such as He from hydrogen or protons, the energy released per gram of material *i. e.*, in the synthesis of helium from hydrogen would be nearly ten times more than that released in the fission of the uranium nucleus. The principle underlying the preparation of the hydrogen bomb is the synthesis of matter. In this the isotope of hydrogen called Tritium plays an important part. An actual hydrogen bomb will be about as effective as 2 million tons of T. N. T., whereas the uranium bomb is only equal to 2,00,000 tons of T. N. T. Considerable amount of work is also going on for the practical utilisation of atomic energy and much progress has been achieved in this direction.

Before concluding, I wish to make two observations. Before 1940, research in nuclear physics was supposed to be a luxury and was considered to be of no practical value except for satisfying the aesthetic sense of the atomic scientists. Very little encouragement was therefore given. After 1940, the situation has completely changed. Large sums of money are being spent on work connected with nuclear physics because of its extreme usefulness both from practical and political points of view.

The second observation concerns with the scientists working in this field. It had been the privilege of the scientists the world over to communicate freely with fellow scientists and to publish the results of their scientific investigations wherever they like. Of late this does not apply to those working in the field of nuclear physics. Most of the countries like U. S. A., U. K. and Russia have imposed a ban on the free publication of the results of researches in nuclear physics. Scientific freedom does not exist. The net result is that considerable progress has been made in this field during the past ten years. We do not know now even 1/10th of what has been done and achieved in the field of nuclear physics.

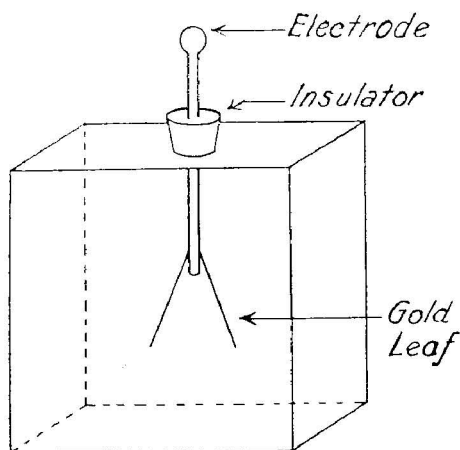
LECTURE—II

Detection of Nuclear Particles

In this lecture, I shall give a brief resumé of the different methods employed for the detection of nuclear particles and radiations. By nuclear particles, I mean electrons, positrons, protons, neutrons, deuterons, alpha particles, mesons, etc. Because of their smallness in size, namely of the order of 10^{-13} or 10^{-13} cm, they cannot be observed even with the aid of the most powerful microscopes. The term radiations is applied to highly penetrating gamma rays. These rays cannot also be detected visually. All the methods of detecting nuclear particles devised so far are based on the effects produced by the charge and speed of the particles in moving through matter. Radiations and neutrons which possess no charge must be detected by secondary effects in which they cause charged, rapidly moving particles to appear. When the charged particles pass through matter, they collide with atoms and a process known as 'ionisation' takes place. Each ionisation process gives two ions. These collisions which result in ionisation afford the means by which the detection of nuclear charged particles is effected.

1. GOLD LEAF ELECTROSCOPE.

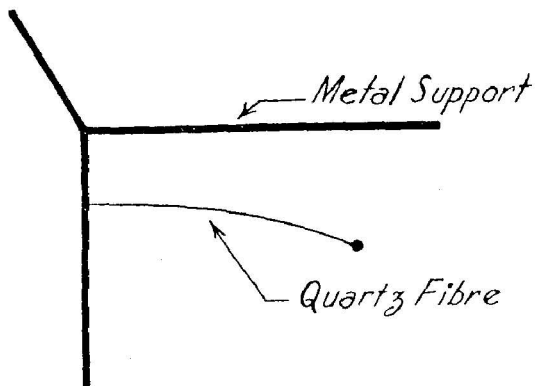
One of the earliest methods of detection is the one using a gold leaf electroscope. It is a simple instrument and has played a major part in the study of radio-activity. It consists of a rectangular metal box with an insulated electrode passing through the lid. See Figure 1. To this are attached two gold leaves. One side of the box is open and is covered by a very thin foil of aluminium through which the radiations to be detected enter. When the electrode is charged the leaves will diverge. Gravity opposes the deflection of the leaves. It will remain in that condition indefinitely. But if the space near the leaves is ionised, the ions in the air are attracted to the charged leaves and in this way tend to neutralise



their charge and cause the leaves to collapse. The rate of collapse of the leaves which could be measured with the aid of a microscope gives a measure of the ionisation current or the particles entering the chamber. It does not have a linear scale. This can measure only an intensity of radiation and cannot count individual particles.

2. THE LAURITSEN ELECTROSCOPE.

The advantages of the simplicity of the gold leaf electroscope are retained and the advantage of greater sensitivity is added in a beautifully simple quartz fibre electroscope designed by Lauritsen. The heart of the instrument is shown in the diagram (Figure 2.) It consists of a small metal frame shaped as shown with a quartz fibre (gold sputtered) attached to it.



A little T is made on the end so as to make the end visible. When a charge is given the repulsive force between like charges will cause the fibre to bend away from the metal support. In place of gravitation, the elastic force of the quartz fibre is used as restoring force. In spite of the delicacy of the fibre, the instrument is remarkably rugged. The scale is nearly but not quite linear; it is

still necessary to carry out the timing over the same range of scale at each observation. The sensitivity of the instrument is such that a millicurie at a distance of a meter produces a motion of about 5 Scale divisions per minute, the background due to cosmic rays being 5 per hour.

The universally employed particle and radiation counters are – the ionisation chamber, the proportional counter and the Geiger-Muller counter. All these devices depend essentially on (a) the production of ions in a gas by the incident particle or radiation, (b) the separation of the oppositely charged ions and their collection on to the oppositely charged electrodes by means of an electrostatic field. Certain broad features are common to all these instruments. They are all gas filled instruments, the gas being filled

at a definite pressure. They invariably consist of a collector electrode (usually the anode), surrounded by an outer electrode; an electrostatic field is maintained between the electrodes. Finally, the instrument supplies the electric pulse to some recording device. The combination has certain a resolving time T . The instrument can be used (a) as a current source, when the average rate of arrival of particles $N/\text{sec} \gg I/T$ (b) as a counting device when this average rate $N < I/T$.

3. THE IONISATION CHAMBER

The essential parts of an ionisation chamber are (a) two electrodes at different potentials, the collector electrode being close to the ground potential, (b) the heavy insulator supporting the collector electrode, (c) the guard ring surrounding the collector electrode held at ground potential and (d) the insulator separating the guard electrode from the high voltage electrode. An α -particle of one Mev energy will produce 30,000 ion pairs. This is equivalent to a total charge of about 10×10^{-15} of a Coulomb. An ordinary galvanometer is quite incapable of measuring such small currents. One has therefore to make use of some kind of electrometer or vacuum tube amplifications. A sensitive electrometer can detect a charge of 10^{-16} Coulomb. Hoffmann has designed a "duant" electrometer which has been used in several important nuclear investigations in the early days. In recent times this method, though by far the simplest in principle, is not used. The reason lies in the fact that the electrometer, which is far from rugged, requires skill and experience to set up and keep operating.

Special chambers can be constructed for special purposes. These ionisation chambers are specially designed for the observation of α -particles even in the presence of a background of ionisation much more intense than that due to α -particles. Such discrimination is possible because the ionisation due to a single α -particle was formed practically instantaneously and the ionization pulse is much bigger than that due to β -rays and the charge is collected in about 2×10^{-4} sec. These chambers are not useful for detecting electrons and γ -rays.

Linear Amplifier :—

In place of the electrometer, the ionisation chamber can be coupled to the grid of the first valve of an amplifier. The small change of potential at the input electrode is amplified linearly several hundred times and is fed on to a recorder. It is desirable to collect as much of the charge as possible on an electrode having a minimum capacity. The insulation of the collecting electrode must be of the highest order; quartz, amber, sulphur or sealing wax is generally used. Ionisation chambers are very liable to be microphonic; this is one of the most important points to be considered in the design.

Five magnifying stages are generally more than sufficient to give all the amplification that can be usefully employed. Only three stages of the normal amplifier are used to give a very high voltage gain. Amplification is sacrificed in the first stage in order to secure as low a ratio of background to pulse as possible. The final stage is designed to give maximum output power and not the maximum voltage gain. The overall amplification is 10^6 . The H. T. supply to the amplifier should be highly stabilised if it is from the mains or otherwise, it should be taken from a battery. Linear amplifiers with ionisation chambers are not easy to operate even though they are more rugged than electrometers.

Electrometer Tube Amplifiers :—

The ordinary linear amplifier will give rise to considerable background noise due to appreciable grid currents of the triodes. The electrometer tubes have been devised to get over this difficulty. The design and operation of the electrometer tube is such that all these sources of grid current are eliminated or reduced to a minimum. Such tubes provide large current amplifications and their output can be made to operate a galvanometer. The most commonly used tube is FP54. The plate voltage is of the order of 6 volts so that no ionization takes place in the residual gas. The grid current is less than 10^{-17} amp. For satisfactory operation of an electrometer circuit, a number of precautions has to be observed, such as careful shielding, good heat insulation, etc. Electrometer tube circuits are used for detecting very weak sources of alpha particles.

4. THE PROPORTIONAL COUNTER

In the ordinary ionization chamber if a strong electric field is imposed on the liberated electrons, they will immediately be accelerated, and if the field is strong enough they may acquire so great a speed before an encounter with a neutral atom that they can in their turn produce secondary ionization. By this cumulative process, a very rapid accumulation of electrons takes place. It can reach a thousandfold, thus reducing the amount of amplification required from a vacuum tube amplifier, to the point where a simple, stable, easily constructed amplifier will suffice for the detection of the ionisation current produced by the incoming particle. This type of multiplication of charge is called "gas amplification". This principle is made use of in the construction of proportional counters and also in Geiger-Muller Counters to be described later. The proportional counter consists of a copper or brass tube with a central wire kept at a high positive potential with respect to the outer cathode. The counter is usually filled with methane. The potential difference between the cathode and the central wire is such that charges collected by the latter or the voltage pulses given out are approximately proportional to the ionising power of the particles counted. These voltage pulses can be amplified in the usual way by an amplifier. The proportional counter is very useful for detecting alpha particles and protons. A modification due originally to Rutherford and Geiger and known as Geiger Counter or Geiger-Muller Counter supersedes the proportional counter for detecting electrons. Historically the Geiger Counter was devised before the proportional counter. The latter, however, will count at higher rates than a Geiger Counter.

5. GEIGER-MULLER COUNTER

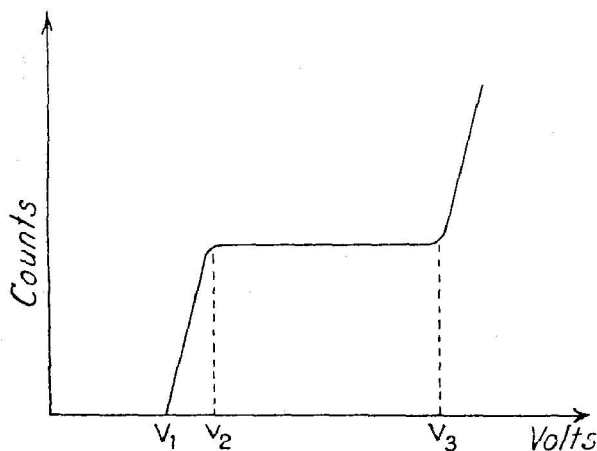
Nothing has been so extensively used for detecting nuclear particles as the Geiger-Muller Counter. As already indicated, it is similar to the proportional counter except for the fact the central fine wire is kept at a much higher voltage. It is filled with a gas mixture at a low pressure. In the Geiger-Muller Counter, the ionization produced by the radiations passing through it acts as a trigger to set off a momentary discharge through the tube. Such a method of detection is very sensitive. Both strong and weak rays produce equal effects. One serious defect is that the discharge will

persist permanently and the counter will become ineffective, if the discharge is not interrupted. The consideration of this matter is of great importance in understanding the operation of the Geiger Counter. This is carried out in an elegant way. The counter is connected to the H. T. supply through a high resistance (see Figure 3). The entrance of an electron then precipitates a discharge, but the resulting current must pass through R and in so doing

sets up a fall of potential across R which greatly reduces the potential across the counter A , and the discharge is extinguished. The counter then gradually resumes its former condition of high tension and is ready to discharge on the arrival of a second electron. The presence of a very high resistance in series introduces a long time lag for

the counter to come back to normal. In modern G. M. Counters the quenching is carried out by some organic vapour like alcohol etc. The filling in a modern G. M. Counter consists usually of 9 cm. of argon and 1 cm. of alcohol vapour.

The voltage pulse from the Geiger Counter could be transmitted to a



single stage amplifier through a small condenser and fed on to a mechanical counter. Each counter has a characteristic counting curve. (See Figure 4.) At V_1 , it starts to count. Between V_2 and V_3 the number of counts remains constant and this region is called the plateau; when the voltage is increased above V_3 , counting increases

rapidly and finally a continuous discharge takes place. A good G. M. Counter should have a plateau extending over 300 Volts. The usual voltages applied to the counter are of the order of 1000 - 1100 Volts. This is supplied from a specially designed highly stabilised high tension unit.

With the aid of a G. M. Counter it is possible to count the individual particles entering it. These counters are mostly used for β -rays and γ -rays, although they could also be used for alpha particles. There are different types of counters specially designed for γ -rays, β -rays, soft β -rays and very soft β -rays. There are also gas flow counters. Once the radiations enter the counter, it is difficult to distinguish between different types of radiations. Sensitiveness of the counter will depend very much on the nature of radiation to be studied. For γ -rays, usually higher pressures and inert gases (Xenon, Krypton) are used. For neutrons, boron fluoride gas is used and also paraffin blocks. The G. M. Counter is a simple device. Nevertheless, probably no apparatus in modern physics has had more study from the technical side or appeared in more diverse successful forms than the Geiger counter. The research worker may intentionally make up a Geiger Counter following the best instructions given in books and still fail to make it work satisfactorily. There are considerable difficulties in the construction of good counters. Cleanliness and smooth surface are very important considerations. A considerable amount of trial and error is involved. There is therefore no infallible set of rules which when followed will guarantee perfect operation of a counter. The proof of the pudding is emphatically in the eating. One author has put it, "Preparation of Geiger Counter is on a par with cooking a meal". Experience makes a difference.

Every G. M. Counter gives a natural or background count due to cosmic rays. This is of the order of 1 per minute of each square centimetre of counter area. Geiger Counter technique allows coincidence counting, to show whether two nuclear processes take place at the same time or not.

6. CONDUCTIVITY CRYSTAL COUNTERS

In the year 1945, Van Heerden showed that a crystal of silver chloride can be used for counting purposes. When any nuclear

particle falls on a plate of silver chloride crystal, the two faces of which are kept at a difference of potential, ionisation take place and a small current passes through the crystal plate as if it is made conducting. This could be amplified and recorded in the usual way. The counting property is enhanced by maintaining the crystal at a very low temperature. Other crystals which have similar counting properties are diamond and thallium halides. The conduction crystal counter has the following advantages :—

1. Its high stopping power makes it useful for detecting radiations of high penetrating power and for use in a narrow space.
2. Its fast response speed makes it suitable for high counting rates. It is capable of resolving nuclear events at intervals greater than about a microsecond.
3. The output pulse height is proportional to the energy of the incident particle.
4. Its sensitivity and efficiency are relatively high, especially for γ rays.
5. It needs no window and therefore absorption by the window does not arise.

Finally the counter has been found suitable for the detection of single α and β rays, γ and X-ray photons, and neutrons.

All these advantages which make the counter potentially more useful than gas filled detectors are also shared by the scintillation crystal counter to be described next. In recent years, the latter has become a standard detector for use in nuclear experiments, while the conduction counter is still beset with certain disadvantages and practical limitations. Foremost among these is the formation of a space-charge field in the crystal as the bombardment of ionising radiation proceeds. Heating the crystal or irradiating the same with infra-red rays is employed to overcome space charge difficulty. The other disadvantages are the following :—

1. Only a few crystals can be used at room temperature.

2. Variations occur in counting efficiency from crystal to crystal and even in different parts of the same crystal. This is particularly true in diamond.

3. The nature of the surface of the crystal greatly affects the sensitivity to low energy radiations.

Conduction crystal counters cannot take their place yet as standard tools in nuclear physics largely on account of the formation of space charges. But solid crystal counters have shown a new way to investigate the crystalline state.

7. SCINTILLATION COUNTERS

One of the earliest methods of detection and counting of individual charged particles and nuclear transmutations is by the use of scintillating materials. Zinc sulphide crystal containing a slight contaminant of copper was spread on a screen and when the charged particles are allowed to impinge on that, light pulses were emitted and these scintillations were viewed through a microscope. Such a technique had to produce enough light to be seen in a microscope, and the small number of quanta produced lasting for a very short time made counting very laborious indeed. But the pioneering experiments of Rutherford and his school were done in the early stages with this technique. This technique is tiring, slow and unreliable and was abandoned as soon as electric counting methods were available. For quite a long period this technique came to disrepute. But in recent years, the advent of the photo-multiplier tube which is sensitive to a single photon has again brought the usefulness of scintillation counters into the lime light. Kallmann discovered that naphthalene and anthracene crystals produce and transmit light which will excite a photocathode, when ionizing radiations enter. Phenanthrene, sodium and potassium iodides, calcium tungstate, stilbene, and polystyrene are additional substances which are suitable for this purpose.

The mode of action of a scintillation counter may be described as follows :—

The charged particles in ploughing through the naphthalene crystal ionises many atoms and ofcourse breaks many chemical bonds. A fair fraction of the recovery process after this devastation takes the form of the return of electrons to atoms with the attendant emission of light. This light is made to fall on the photocathode of a photomultiplier tube. It then produces one or more electrons in the sensitive cathode of the photomultiplier tube. These electrons are accelerated by a voltage of 80 volts to the next electrode whose surface is such that each 80 volt electron produces several slow electrons. This is multiplied until a considerable avalanche reaches the last electrode and a readily measurable current pulse is produced. An ordinary counting unit could be used.

The advantages of the scintillation counters are the following :—

1. It is exceedingly simple to operate and is perhaps the easiest counter of all to be made to work provided one gets a photo multiplier tube.
2. It can operate in vacuum thus eliminating troublesome thin foil techniques.
3. It delivers a pulse roughly proportional to the ionization produced by the incident radiation thus affording a means of distinguishing between different kinds of radiations, which a Geiger Counter cannot do.
4. It can be made of considerable thickness. This renders it highly sensitive to γ radiation.
5. Such counters appear to act very rapidly so that the response times of the order of 2×10^{-8} second are possible.

The great disadvantage of the scintillation counters is the thermal noise which produces a background count of about 1000/min. This can be reduced by cooling the photo-tube and also by having 2 photo-tubes looking at the same crystal.

Recording Equipment :—

So far, I have not said anything, about the actual recording. It is necessary to provide a recording equipment with counting ionization

chamber, the proportional counter, the G. M. Counter, the crystal counter and the scintillation counter. The simplest is the thyatron recorder. The pulse from the counter after suitable amplification is fed on to the thyatron circuits and operates a counting rate meter. When the rate of counting becomes large, it is necessary to use scaling circuits. These operate in such a way that only every tenth or, every eighth impulse is passed on to an electromechanical recorder. The general principle most commonly employed is that of the "scale of two" counter introduced by Wynn-Williams. Such a scale of two has a very high resolution since it contains no moving parts. Scales of Two arranged in cascade, form counting units. Each successive stage in such a counter divides the counting rate by two. Considerable development has taken place in scaling circuit. There are scales 128, 512, and 100 etc. In place of a mechanical counter, one can use a counting rate meter for steady reading especially when the counting rate is very high.

The various counters described in the previous sections can also be coupled with suitable electronic circuits to a cathode ray oscillograph for visual observations of the pulses.

Fluctuations in Counting :—

All nuclear transformations are based on probability. It is pure chance when the individual event takes place. A very large number of such events, when averaged will show a clear and accurate manner of decay, but the fact remains that the random nature of the individual process underlies the whole general phenomenon. The percentage error becomes less the larger the number of counts taken.

8. THE CLOUD CHAMBER

This is almost certainly the most widely known device for the detection of nuclear particles because it gives such a graphic portrayal of the path of a nuclear projectile. C. T. R. Wilson observed that ions can act as centres for the formation of condensed droplets in a supersaturated vapour. Rapid adiabatic expansion of a saturated vapour causes a fall in temperature which carries the vapour below the dew point. If the vapour is clean, particularly

if it is free from dust, the state of supersaturation is maintained unless some ions are present. Droplets are formed on these ions and thereby make the presence of the ions visible. By illuminating the vapour after expansion, photographs can be taken and any interesting events may be permanently recorded. The tracks of the different particles will be different. One great advantage of using a cloud chamber is that with the aid of an electromagnet, it is possible to determine the nature of the charge and mass of nuclear particles. The cloud chamber is an indispensable tool for cosmic-ray studies and also for investigating nuclear transformations, i. e., to demonstrate how a certain nuclear reaction proceeds. Neutrons can also be detected by employing hydrogen containing gas inside the cloud chamber. They eject protons whose tracks could be photographed.

A very serious defect of the cloud chamber is that although the sensitive time is only $1/30$ second, nearly 20 seconds should elapse between expansions. During this period nothing could be recorded. It is therefore only $1/6\%$ efficient. It is also a very complicated equipment and difficult to construct.

An improvement in cloud chambers that permits continuous sensitivity is the diffusion type of cloud chamber. Here supersaturation is achieved by the diffusion of alcohol or water vapour from the warm roof of the chamber downward through an inert gas (argon) to the cold floor. Since the temperature gradient covers the "dew point" temperature of the vapour used, condensation occurs on ions in a sensitive layer of several inches depth near the floor of the chamber. A pulsed electric field is applied to sweep the ions at regular intervals and steady state conditions are established very rapidly.

9. PHOTOGRAPHIC PLATES (Nuclear Emulsion)

During the past ten years, photographic detection using specially prepared nuclear emulsion plates has come into vogue. It has always had considerable appeal because it offers nearly the same advantages as the cloud chambers, namely the ability to see the process occurring and to record it permanently. This technique was first used by Mariette Blau. Recently as a result of the efforts of Prof. Powell and his collaborators,

emulsions of sufficient thickness and fineness of grain have been produced for a wide range of use. Such emulsions must be developed with great care, each process taking several hours. The ionising particle causes the dislodgement of electrons in the emulsion. These electrons are held in position so that a latent image is formed which remains for a period of weeks or months. Development by a reducing agent then causes each grain containing the dislodged electron to blacken. Since the total path length of a nuclear particle in the emulsion is very short the grain size must be small or no kind of track is produced. Nuclear emulsion photographs appear similar to those of cloud chamber but on a miniature scale.

The tracks are observed with the aid of a high powered binocular microscope which needs to be focussed at different depths in the emulsion. It is the tediousness of this work which detracts from the photographic method. Psychological approach is necessary. Observing in a group in undarkened room, moral rises each time an exciting process is uncovered and competition stimulates discovery while providing for healthy scepticism. It is very easy to take the photograph, but it is very laborious and time consuming for scanning even a single negative. Interpretation of an observed star is a highly specialised job.

Detection and counting of nuclear particles are carried out now a days mostly with counters or ionization chambers; mechanical counting devices are used to record the results. This method combines maximum sensitivity since it will detect single events with the capacity necessary to obtain accurate results.

If a phenomenon is new and not yet understood it is often very difficult to unravel it by counting only. This is where the cloud chamber proves of the greatest value, since it shows at a glance the kind of particles involved and their interrelations. Had there been no cloud chamber, the discovery of a neutron, the positron and the meson would no doubt have been made, but later with much greater effort.

Considerable advances have been made in nuclear instrumentation during the past 4 or 5 years. The scintillation counter has considerably

replaced the G. M. Counter, both in portable radiation monitors, and in laboratory measuring instruments. This is due to the considerable variety of photomultiplier tubes available, having cathode areas as large as 5" diameter, transit times as short as 5×10^{-12} sec., and sensitivities as high as 100% A per 10^{-6} lumen. Further transistor circuits are becoming more and more popular on account of their compactness and very low power drain. Thus counting-rate-meters, scalars, R. F. power supplies for high voltage, etc. are getting more and more "transistorized". Among further improvements may be mentioned, 'Dekatron' scaling tubes consisting essentially of ten neon discharge points connected to form a scale of ten, and "Trochotrons" for pulse height measurements.

LECTURE — III

Nuclear Machines

IT was explained in the first lecture that nuclear transformations could be brought about by bombarding the nuclei with high energy nuclear projectiles. The higher the energy, the greater the transformation. The projectiles normally used are protons, deuterons, alpha particles, neutrons and also gamma rays produced by high energy electrons. The devices in which these projectiles are accelerated to high energies are called nuclear machines. Modern nuclear machines are more on an Engineering scale than on the Laboratory scale. They are huge and very costly ones and consequently research in nuclear physics has become very costly. Nuclear machines are of different types and one can devote one full lecture for each machine. But in the present lecture, I shall give a brief description of the principle, mode of operation and uses of the different types of machines.

The different types of nuclear machines can be broadly classified into two groups. The first group refers to generators which produce very high voltages required for accelerating charged particles. The voltage from the generator is applied to an accelerating tube or column. The charged particles while passing through the column get accelerated to energies corresponding to the applied potential difference. These machines have

certain advantages. Not only high energy particles could be obtained in large numbers, but they are also more or less homogeneous and steady in energy. They emerge from the apparatus in a parallel beam with little accompanying stray radiation. It is possible to measure the voltage at which the particles are accelerated with great accuracy and to vary it readily over a wide range. The main limitation of these machines is that the maximum voltage obtainable is only 10 M.V.

In the second group of machines, the charged particles are accelerated to high energies by successive accelerations, at each stage the particles getting an acceleration of a few hundred thousand volts. In this way particles of a several hundred million electron volts energy could be produced. The particles coming out of such machines are not homogeneous and are accompanied by large stray radiations. Each machine is designed to produce charged particles of a particular maximum energy which could not be varied at will unlike in the case of electrostatic generators.

I shall now describe the machines under the two groups one by one.

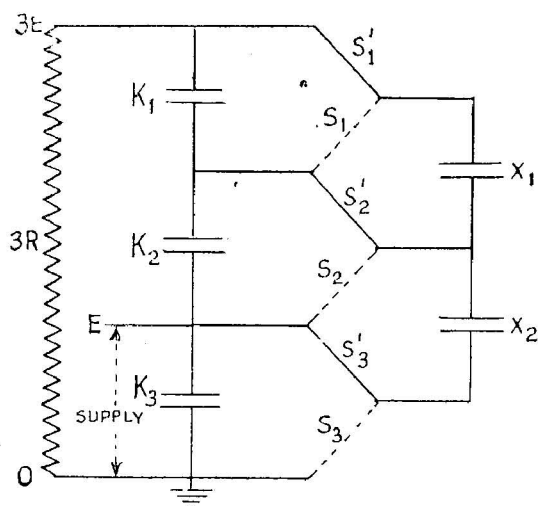
1. LAURITSEN & BENNETT

One of the most common sources of high voltage is the alternating current transformer. Since direct current is usually desired for accelerating particles, the alternating current is rectified by means of two element thermionic tubes. Lauritsen & Bennett were the first to employ a group of transformers in cascade. The maximum voltage obtained by this method was only 1 M. V.

2. COCKCROFT & WALTON GENERATOR

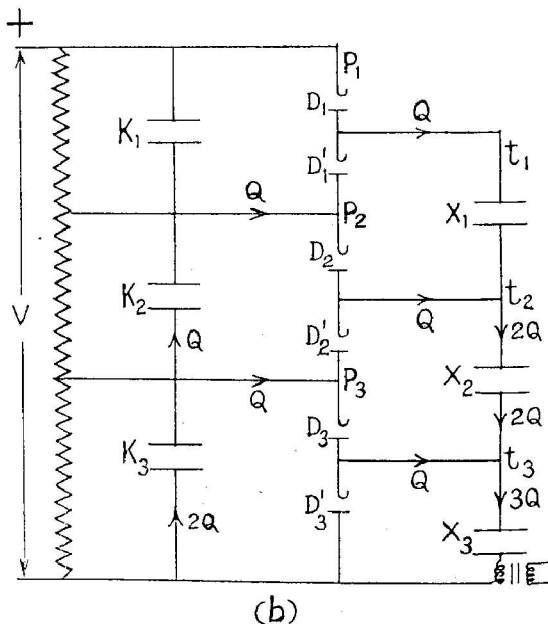
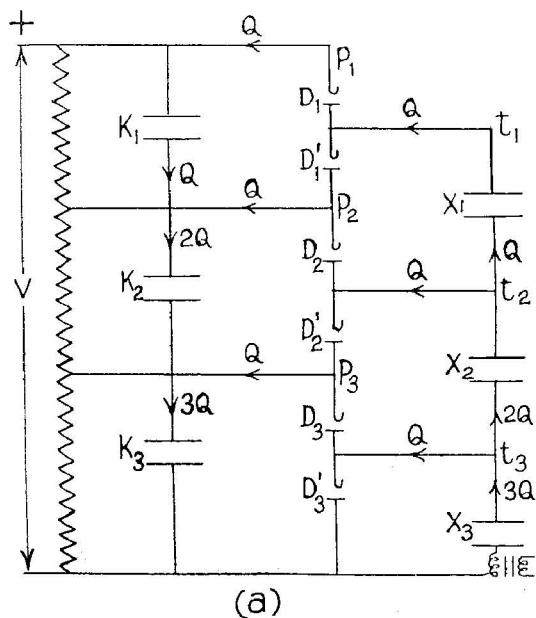
The first successful attempt to construct a high voltage D. C. generator of the order of a million volts was made by Cockcroft and Walton at Cambridge. The generator consists mainly a series of condensers and rectifiers, coupled to a low voltage transformer. The principle of operation is as follows: (See Figure 1.) K_1 , K_2 , K_3 , X_1 and X_2 are condensers. When connections S_3 and S_2 are on, X_2 gets charged to Voltage E . When S'_2 and S'_3 are on, X_3 shares its charge with K_2 each getting a Voltage $E/2$.

When S_2 and S_1 are on, K_2 shares with X_1 , and each gets $E/4$ while X_2



again gets E . When the process is repeated, in due course each of K_1 , K_2 , K_3 will get E and total potential across R will be $3E$. The principle is capable of expansion by adding more condensers. The switching on and off were accomplished with the aid of vacuum tube rectifiers. The connections are shown in Figure 2a and 2b. Instead of a constant D. C. Voltage, an A. C. Voltage from a transformer is

applied. The positions will be as shown in (a) when the transformer potential is near the positive peak value. It is as shown in (b) when the transformer potential is near the negative peak value. In this stage the second set of



rectifiers become conducting and the charging current passes as shown in the Figure. The two sets of rectifiers become conducting or not, depending on

the particular cycle of the A. C. voltage of the transformer. Each rectifier and condenser have to withstand twice the voltage of the transformer. Although the principle is simple, there are considerable experimental difficulties to be encountered. The supply of the heating current to the various rectifiers is a very serious problem. R. F. heating is now adopted in commercial sets. Cockcroft and Walton produced a generator which went up to 0.8 M.V. The high voltage generator is connected an accelerator tube. The ions are produced at one end and are accelerated while passing through the columns. At the bottom end of the column the ions impinge on the target which is kept water cooled. Cockcroft and Walton were the first (1932) to produce artificial nuclear disintegrations with high energy particles. The Philips Electrical Co., in Holland are manufacturing the Cockcroft and Walton type of generators. The biggest machine constructed so far goes up to 2 M.V. The Tata Institute of Fundamental Research is having one going up to 1 M.V. These generators are capable of delivering charged particles of about a milliamperere current. In conjunction with the C-W Generator one has to use an ion accelerator. The power supply to the ion accelerator is a big problem. A generator driven by a belt from below is housed on the top of the accelerator column. This is used to supply power for the ion source.

3. THE VAN-DE GRAAFF OR ELECTROSTATIC GENERATOR

Van de Graaff (1931) was the first to recognize the possibilities of using an electrostatic machine for producing high voltages and the present day electrostatic generator as applied to atomic projectile work is a direct outgrowth of his development research and bears his name. The main components of the Van de Graaff Generator can be enumerated. It consists of a well rounded high voltage terminal hollow sphere supported from ground on an insulating column. A wide endless belt of silk or paper or leather which acts as a charge conveying system runs between this terminal and the ground. Electric positive charge is sprayed by corona on the belt at its grounded end and is transferred by the belt into the hollow terminal, the voltage of which steadily rises. This is connected to the top end of the accelerating column as in the previous case. The terminal potential is given

by $R.I_c$, I_c = net charging current. Rate of rise of V is $R \frac{dI_c}{dt}$. It is of the order of 1 M.V./second. Load current = accelerating tube current + current down support and corona discharges. By adjusting the current carried by the belt and the load current, the terminal voltage may be established at any desired value up to a maximum. Maximum voltage depends on geometry of the top terminal sphere and the surrounding medium. This limiting voltage that can be attained by the sphere of an electrostatic type apparatus is measured by the break-down potential between it and surrounding objects at ground potential.

An essential feature of these generators is that the function of belt charging and charge removing is performed within the field free spaces, existing below the ground plane and within the high voltage terminal. These functions are made independent of the P. D. which may exist between them. The supporting column is usually made up of a series of spaced conducting members or planes with insulated supports in between successive conductors. The descending belt carries an equal amount of negative charge. Thus the efficiency is doubled.

Even for a 2 M. V. generator, the housing problem becomes very serious ; it requires a very large room. Using normal air pressure in the chamber it is not possible to go to higher voltages.

4. PRESSURE ELECTROSTATIC GENERATOR

If the electrostatic generator is housed in a casing, one can increase the ultimate voltage attainable in either of two ways:—(1) by evacuating the surrounding space to a point well below the critical pressure or (2) by increasing the pressure to several atmospheres. The latter possibility has proved to be the more practical, and several installations which operate under pressures up to 10 atmospheres are now completed. The foremost among workers in this line is Herb at Wisconsin. A small leaking column is provided which ensures a uniform potential gradient from E to ground and discourages sparking.

Compressed air is dangerous because of fire. Nitrogen is far better. Other vapours used are sulphur hexafluoride, CCl_4 and CCl_2F_2 . Recent

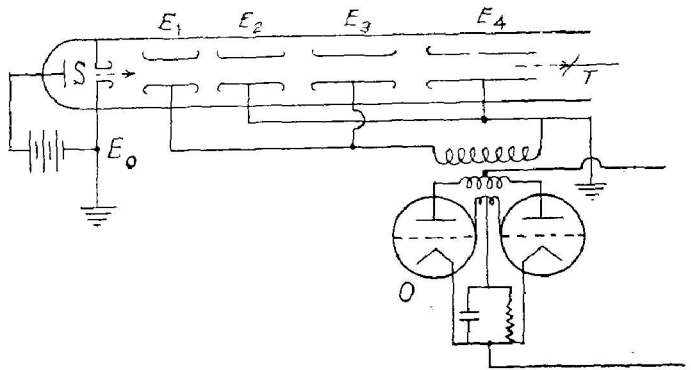
advances are in the direction of higher pressures and greater compactness. Normal column gradient is 1 M.V./foot and terminal tank spacing is 7". Current capacity is 250% A. The close control which one can exert on the voltage makes the electrostatic accelerator ideal for accurate work in nuclear physics, namely, determination of excitation levels of nuclei. Machines designed for 12 M.V. are now under construction at Los Alamos and in M. I. T. 3 M.V. ones have been constructed and working satisfactorily in England.

MULTI-TRANSIT ACCELERATORS

5. LINEAR MULTIPLE ACCELERATOR

The simplest apparatus utilizing indirect method is the linear multiple accelerator, first demonstrated by Wideroe and developed in America by Sloan and Lawrence. The name aptly describes its mode of operation. The main features are shown in the Figure 3. The alternate cylinders are connected to the ends of a coil which is inductively coupled to the tank current of a high frequency oscillators. An alternating potential of several thousand volts is thus produced across the gap between the cylinders.

Inside each cylinder the particles travel in field free space. While they pass from one cylinder to the other they are accelerated. If the period of oscillation is twice the time taken by the particles to travel each cylinder, there will be resonance. As the



particle gains in velocity it is necessary that successive cylinders have longer and longer lengths so that the time taken by the particles to travel from end to end remains constant. With the R. F. available in 1932 unusually long cylinders were necessary. This machine could not be developed for high energies. Another glaring defect in this Instrument is the

difficulty of trying to achieve both "axial" and "phase" stability. With the invention of the cyclotron, interest in linear accelerators disappeared until the radar techniques of World War II made it appear feasible to obtain high energy protons in a reasonable space. In 1948, Alvarez completed an installation at California which produces 32 Mev. protons in an apparatus 40 ft. long. The apparatus looks complicated but the basic principle is the same. Apparatus for electrons of higher energy are also in use. The main advantages of the linear accelerator for very high energies are the following:— The low radiation loss by the particles at all energies in contrast to magnetic devices, and the ease with relatively large mean currents might be injected and ejected. The cost is proportional to a linear function of the peak energy of the particles, whereas the cost of any form of cyclic accelerator is proportional to at least the square of the peak energy if not to its cube. The mean currents of a betatron or synchrotron are one sixtieth to one six hundredth of those to be expected from a linear accelerator. Machines capable of producing energies from a few Mev to 1,000 Mev are being designed. The most serious limitation is the lack of suitable valves with pulsed powers.

The basic aim of all linear accelerators is to produce a progressive wave of controlled phase velocity less than or equal to the velocity of light with a component of electric field in the direction of propagation of the wave. Particles injected in the correct phase into a wave of this type will gain energy from the wave and form stable bunches. It is one of the characteristics of the circular smooth walled wave-guide that waves of this type may be propagated along them but with phase velocities greater than the velocity of light. The resonators oscillate in such a way that the particle passes each resonator centre when the accelerating field is a maximum, that equal power is fed into each resonator and that the size of the coupling holes between resonators is negligibly small. A 300 Mev linear accelerator will be roughly 450 meters long.

Regarding the future role to be played by linear devices, it appears that their greatest utility will be in the Bev. (Billion electron volt) electron range. For lower electron energies, the betatron and the synchrotron may prove more economical. The Van de Graaff machine, cyclotron, frequency

modulated cyclotron, and proton synchrotron appear to blanket the entire range of heavy particle energies.

6. THE CYCLOTRON or the CYCLIC ACCELERATOR

This extraordinarily successful device employing the principle of multiple acceleration is the invention of Lawrence at the University of California. The heart of a conventional cyclotron consists of a large circular vacuum chamber, inside which are placed two hollow semi-circular electrodes called "dees" because each is shaped like a Capital D. These dees are situated with their straight edges parallel and about an inch apart, the unit forming an approximate circle when viewed from above. See Figure 4. The dees are coupled to a source of radio-frequency voltage, usually through the intermediary of a coupling link known as a quarter-wave line. The dees form the high-voltage end of the quarter-wave line. Ions are produced at the centre of the chamber between the dees. The whole chamber is placed between the pole faces of a large electromagnet capable of producing a field in the neighbourhood of 16,000 gauss. The operation is as follows :—

The chamber is evacuated to a pressure of 10^{-6} mm of Hg. The gas, ions of which have to be accelerated, is now introduced into the chamber. A cone of ions is formed at the centre of the chamber. Let us concentrate at one ion.

Let it be formed at P. Dee A is at -ve voltage peak of the R. F. cycle and hence dee B is at its +ve peak. The ion being +vely charged will be drawn to A and will pass into the hollow field free interior, acquiring a small velocity. However, the magnetic field does act on the ion, exerting a force on it at right angles to its direction of motion. This force will cause the ion to move in a circular path. If by the time the ions have completed a semicircle the dees have reversed charge, the ion will again be accelerated across the gap and enter the interior of B. Each time it passes from within one dee to the other the ions gain an increment of kinetic energy equal 'e' multiplied by the momentary voltage difference between the Dees (250,000 V.)

The Radius of the path is given by $r = \frac{mvc}{eH}$ (1)

and angular velocity $= \frac{eH}{mc}$ (2)

The greater the velocity, the greater the radius of the path the ion traverses, The ion travels in ever widening circles until it reaches the exit slit in dee A. when it is pulled out by a deflector plate D - kept at a potential of the order of 50,000 volts.

It will be seen from equation (2) that the angular velocity of the ions is independent of the linear velocity, *i.e.*, an ion requires the same time to complete one revolution whether moving near the centre of the chamber or close to the periphery. The time of one revolution is the same, no matter what the diameter of the circular path is. When the time for one half circle is the same as that for one half cycle of the radio-frequency field, the condition is spoken of as resonance.

If the Dee Voltage is 250,000, the ions have to make 50 revolutions *i. e.*, about 100 meters total path in order to attain an energy of 22 Mev. One might think that ions might get scattered by the time they pass through this long path. There are two factors which prevent this. They are the electrostatic focussing at the Dee edges and the magnetic focussing. The former is an earlier effect, while the latter is later effect appearing at higher energies. Towards the periphery the field has a sizeable horizontal component. Above the median plane this horizontal component is directed in ward; below it is out ward. The ions moving either above or below the median plane will be forced back towards the middle by this horizontal field component. The magnetic focussing is more effective than electric focussing since the former acts always, while the latter acts only in the gap between the dees. The focussing in a cyclotron is so effective that the ions impinge an area of about 1 sq. cm. The usual constants for a 37" cyclotron are the following. With $H = 17,000$ gauss, & 25 meter for R. F. frequency, the resulting deuterons will have a maximum energy of 10 Mev. The biggest cyclotron of the simple type which is in successful operation is the 60" one at Berkeley, U. S. A.

7. THE BETATRON or MAGNETIC INDUCTION ACCELERATOR

The cyclotron is limited in use to protons, deuterons, alpha particles and other such heavy ions whose velocity remains well below the speed of light. This restriction is necessary to maintain the resonance of the electrical oscillations with the angular motion of the ions.

$$f = \frac{eH}{2\pi mc} \quad f = \text{frequency of the R. F. Field.}$$

This makes the cyclotron useless for acceleration of electrons, since they double their mass at less than $\frac{1}{2}$ Mev energy and the resonance condition gets annulled.

This restriction does not apply to the case of a machine called the Betatron which is designed especially for accelerating electrons to very high energies. It was invented by D. W. Kerst. In general appearance, the betatron resembles a cyclotron. Electrons are drawn round a circular track keeping them in the track by means of a magnetic field. Unlike the cyclotron track, this track is of constant radius. No external electric fields are acting on the electrons other than that produced indirectly by increasing magnetic field rather slowly from zero to a peak value. The vacuum chamber is like an inflated rubber tube called Doughnut. It is only a few feet in diameter and is placed between the poles of a large laminated core electromagnet excited by alternating current. The frequency of the alternating current may be 60 cycles or several hundred per second. When the electrons are first injected their speed is small and the magnetic field is almost zero. Then as their momentum increases, the magnetic field increases proportionally so as to keep the radius of the path of electrons from changing.

$$\frac{mv}{H} = \frac{re}{C} \quad (3)$$

i. e., if the ratio of the momentum, mv , to the magnetic flux density is kept constant the radius r remains constant. The momentum of the particles is progressively increased by the increasing electric field produced by the increasing magnetic flux through the area bounded by the electron path. It is well-known that a changing magnetic flux will induce an E. M. F. into a closed circuit which links with it. It is not so often recognized that a

changing magnetic flux will set up an electric field along any path which links with the flux as in this case, even though no conductor is present. This electric field accelerates the electron up to its maximum momentum. If the magnetic flux is denser near the centre of the poles than towards the edges, so as to make its average value within the path twice as strong as its value along the path, and if the flux everywhere increases at the same rate, then the electrons will continue to circle the same path from the start to the finish, when the flux density H has reached its maximum value. This is realized in practice by introducing an air gap. A burst of electrons is accelerated in this manner for every cycle of the A. C. When they attain the maximum energy, they are deflected out of their circular path on to a target. The only product is X-rays of γ wavelength. The problem of focussing the electrons is more difficult. If the magnetic field diminishes with radius according to $H \propto (1/r^n)$ where n lies between $\frac{1}{2}$ and 1, there is automatic focussing. Betatrons up to 300 Mev. have been constructed and are in use.

In the energy range beyond 300 Mev., a serious limitation in the design of a betatron arises due to the radiation of electromagnetic energy by the electrons moving in a circular path. Energy radiated is proportional to the 4th power of energy. Once the radiative effect becomes of some consequence, the electrons no longer remain at the equilibrium radius but start spiralling inward. Because of this factor it is believed that 500 Mev. represents the maximum energy attainable with a conventional betatron.

In the cyclotron, the effect of the relativistic change of mass of the particles at high energies is to upset equation (2) i.e., the constancy of angular velocity will not hold good. The proportional changes of mass of a deuteron for two energies are given below :

$$\text{for 1 Mev. deuteron, } \frac{m-m_0}{m_0} = 0.1\%$$

$$\text{for 200 Mev., } \frac{m-m_0}{m_0} = 11\%$$

If the frequency of rotation has to be kept constant, the magnetic field must increase as the ion moves outward. McMillan in U. S. A. and Veksler in Russia showed that a controlled variation of certain phase—stable orbits

could be utilised to provide a simpler and far neater solution to the problem. In fact this general concept applies equally well to the acceleration of heavy particles and electrons and is so powerful that one is able to design machines in the Bev. region with full confidence of success.

The effect of increased mass is to slow down the particles, to cause delay in reaching the Dee end and to produce slower acceleration until they come to the equilibrium position of no acceleration. There would be a circulating beam of deuterons trapped in the equilibrium orbit. McMillan and Veksler showed that if the energy associated with this orbit were changed adiabatically by varying the magnetic field or the oscillator frequency, the particles circulating in this orbit would automatically keep in step with the change (provided the change were slow compared to the time required for the particle to make a revolution) and thus particles could be accelerated to very high energies irrespective of any relativistic change in their mass. Three new types of accelerator designed and constructed which embody this idea are (1) the frequency modulated cyclotron (2) the synchrotron and (3) the proton synchrotron.

8. FREQUENCY MODULATED CYCLOTRON

When the particles are in equilibrium orbit with no further increase in energy, the oscillator frequency is decreased by a small amount. The particles again gain in energy and move in a larger circle. This trick can be repeated again and again. In practice the frequency is decreased smoothly, the equilibrium orbit expanding to larger and larger radii with the ions following obediently attaining higher and higher energies. Finally the ion pulse reaches the periphery of the dee where it may be directed against a target. The frequency is brought back to the original value to trap another bunch of ions and to accelerate them is varied again as before. At California with the 184" machine, the R. F. has been modulated up to 2000 times a second by means of a rotating condenser in the dee line. We get only 2000 bursts of ions per second instead of 20 million obtained from a conventional cyclotron. The radio frequency decreases from 11.5 to 10.4 megacycles per sec.

9. THE SYNCHROTRON

As already stated the principle of phase stability also governs the operation of the synchrotron. However, since the synchrotron is designed to produce high energy electrons as opposed to protons, deuterons and the like, there are differences in construction* and operation between the synchrotron and the frequency modulated cyclotron. Instead of decreasing the frequency of the R. F. field as in the previous case, the magnetic field H is increased and thereby resonance is maintained. Another difference lies in the relative magnet geometry. In a large frequency modulated cyclotron for accelerating heavy particles, magnetic field area is mandatory. On the other hand, if H varies with m , so that m/H is constant, an electron will experience practically no change in orbit radius in going from 2 Mev. to 300 Mev. Most synchrotrons operate initially as a betatron. Difference between the two is the following :—

(1) the synchrotron requires only a slight amount of magnetic flux inside the electron orbit and (2) it has a radio-frequency electrode in the doughnut which serves to boost the electrons to high energy after the betatron action has spent itself. There is no such external electric field in the betatron.

The operation of the synchrotron is as follows :— A pulse of 30–60 Mev. electrons is injected into the doughnut as the magnetic field passes through zero. These electrons are quickly accelerated to 2 Mev. by the betatron principle, at which point the flux bars become saturated even though the field through the doughnut continues to rise. The R. F. oscillator is now turned on and the electrons receive an increase in energy each time they across the radio-frequency electrode gap, their velocity remaining constant at C , but their mass becoming greater. The oscillator frequency is kept constant. The phase stability functions satisfactorily and it keeps H/E a constant.

300 Mev. synchrotrons are operating successfully. Since the principle of phase stability is able to compensate for energy radiated by the electrons so long as the amount radiated is small compared to that gained per turn, it is quite possible to construct machines operating in the Bev region.

10. PROTON SYNCHROTRON—BEVATRON or COSMOTRON

This is a heavy particle accelerator and is a combination of frequency modulated cyclotron and synchrotron. For producing 6 Bev. proton in a frequency modulated machine, magnet pole piece should have a diameter of 100 feet. Construction of such a magnet is impossible. In the proton synchrotron, one varies not only the magnetic field but also the frequency of the R. F. oscillator. One 1.3 Bev proton synchrotron is working satisfactorily in Birmingham (England). There is one of 3 Bev. at Brookhaven (U. S. A.).

Unlike in a betatron, the magnet power will be furnished by a motor generator with a large fly-wheel attached. One has to supply enough outside power to make up for the magnetic, mechanical and I²R losses in the system. A pulse of protons of 10 Mev. energy is injected into the system from a linear accelerator or ordinary cyclotron. It is estimated that each final pulse will contain about 10^{10} proton, about 5% of those starting the long 270,000 mile circular journey (for the 6 Bev. machine). The acceleration time is 1.75 seconds and the machine will be pulsed 10 times a minute. In betting parlance, the bevatron certainly looks like a "sure thing."

The Brookhaven Cosmotron achieved energies of 3.5 Bev. last year, but recently, due to an accident, the exit quadrant of the magnet shorted out, and is being repaired. A new 25 Bev. synchrotron is contemplated in the next 5 or 6 years. It is designed to use a series of alternate converging and diverging magnetic fields to produce controlled oscillations about the phase-stable orbit and confine the particle beam in a tube of relatively small cross-section. This alternation of converging and diverging fields alternating from section to section is found to have a cumulative convergent effect. The new instrument is to have the same "race-track" design, and the orbit diameter of the 25 Bev Synchrotron will be 600 ft. as compared to the 60 ft. diameter of the 3 Bev Cosmotron.

Other machines suggested are the racetrack, the microtron etc. With such formidable weapons at our disposal it seems a certainty that the nucleus must soon yield up its innermost secrets

II. THE ATOMIC PILE

Before concluding, I want to refer to another novel type of machine which is different from the ones already described. This is the so-called *Atomic Pile* first suggested by Prof. Fermi, or an atomic reactor as it is now called. The Pile or a reactor is a device in which the fission of uranium is allowed to take place at a controlled rate. It consists of metallic uranium mbedded in a moderator which is made up of graphite or heavy water. Blocks of uranium are arranged in the form of a lattice inside the moderator. In such an arrangement the uranium nuclei aresplit up by stray neutrons releasing secondary neutrons. The latter are slowed down by the moderator before producing further fission. This process goes on and the flux of neutron increases. The operation of the pile is controlled by the insertion of the required number of cadmium strips which act as an efficient absorber of neutrons thereby keeping the neutron flux well below the dangerous level. Being an intense source of neutrons, the pile is extensively used for the manufacture of radio-active isotopes of many elements in weighable quantities.

Graphite Ore deposit at Madurai Taluk, Madras State

Beneficiation by flotation methods

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Graphite is an important mineral and is being widely used for the manufacture of crucibles which can withstand high temperatures. It is also increasingly used in the Paint Industry and forms the main ingredient for the black lead of pencils. Graphite as a colloidal suspension in mineral oil is found to have good lubricant properties⁷. Low grade graphite powder is also used in foundry moulds. High quality graphite is used for carbon rods and brushes in dynamos. Graphite deposits have been located in India in the following areas:—The Eastern Ghats, Madhya Pradesh, Travancore, Mysore, Madras and Andhra States. High quality graphite ore with 80% fixed carbon and above is being mined in Ceylon. Ceylon graphite requires little beneficiation and mostly hand sorting and hand cleaning methods are used. The present Indian production is not enough to meet her internal demands; and much of the ore mined is also of poor quality. The process of refining and grading is poor. Cost of production of low grade graphite of 20 to 30% fixed carbon is only Rs. 4/- to Rs. 10/- at the pit. If this poor grade graphite ore can be concentrated even upto 35 to 40% fixed carbon, a much better price can be realised for the same. Hence there is a need for developing successful methods for beneficiation of the low grade graphite ore. Though graphite ore is available in fairly large quantities, only small amounts are being mined. The estimated reserve of graphite at Narsipatnam in Andhra State is more than 30000 tons⁶ and the present annual production is said to be only 157 tons in the Andhra State. The following table gives quantities of graphite ore mined during 1952 in India⁵.

TABLE—I

<i>State :</i>	<i>Place :</i>	<i>Quantity in tons.</i>
Hyderabad,	Warangal.	39
Madhya Pradesh.	Betul.	440
Andhra.	West Godavari.	157
	Chingleput.	510
Mysore.	Kolar.	165
Orissa.	Denkanal.	269
	Koraput.	383
	Patna.	550
	Sambalpur.	368
		2881

The present investigation was undertaken to concentrate the low grade graphite ore available in Madurai Taluk. These deposits have not yet been commercially exploited. These graphite deposits occur over an area of about 10 square miles near a village, Poovanthi, 11 miles from Madurai City. The graphite occurs as disseminated flakes in schist. The ore contains little moisture 1 to 2%, and is easily friable during crushing. It is steel black in colour and opaque even in thin slabs. The largest flakes were about 3 m. m. in size. Proximate analysis of the Madurai graphite ore is given in Table II.

TABLE—II

Proximate Analysis of Ore sample :

Moisture % :	Volatile matter % :	Fixed carbon % :	Ash and silica % :
1.25	3.21	22.4	73.14

During grinding of the ore, it was observed that a maximum of 25.9 % fixed carbon was present in the crushed sample, + 35 mesh and - 20 mesh. The lowest percentage of fixed carbon was given in the crushed ore + 150 mesh and - 100 mesh. The value of fixed carbon was only 14.77%. The percentage of fixed carbon decreased progressive upto + 150 mesh. However, a slight increase was noticed in the sample which passed through

150 mesh. Proximate analysis of the different samples in different size groups is given in Table III.

TABLE—III

Proximate analysis of samples of different sizes obtained from screen analysis :

Passed through :	Retain in :	Weight % :	Carbon % :	Volatile matter % :	Ash and silica % :
20 mesh	35 mesh	35.10	25.9	3.7	70.0
35	65	36.00	20.5	3.028	75.2
65	100	13.65	18.4	2.80	77.5
100	150	7.05	14.77	1.20	83.72
150	200	4.8	17.1	1.20	81.30
200	—	3.4	—	—	—
		100.00			

Flotation methods were used for the beneficiation of this low grade ore using kerosene oil, m-cresol and pine oil as flotation agents. A 500 g. flotation cell, batch type, was used and compressed air was bubbled through from the bottom. Mechanical agitation was used to keep the contents well stirred. About 0.4 % of the frothing agent based on the weight of ore was added. The froth was collected and dried in an electric oven at 105°C. + 1°C. for one hour, cooled and weighed. Flotation trials were conducted with the whole crushed powder of the ore and the results are given below.

TABLE—IV

	Quantity of reagent : lb./cwt. of ore :	Fixed carbon % :	Volatile matter % :	Ash and silica % :
Kerosene oil	0.395	51.82	7.62	40.56
m-cresol	0.51	34.62	6.71	58.67
Pine oil	0.398	31.84	5.92	62.24

From Table III, it may be observed, that higher values for fixed carbon are given by coarser powders + 65 mesh. Hence the flotation experiments were repeated on - 35 and + 65 mesh powder and also on - 65 and + 100 mesh powder. The proximate analysis of the concentrate with these two different sizes is given in Table V.

TABLE—V

Size of sample :	Frothing agent :	Quantity of agent in lbs./cwt. of ore :	pH value of pulp :	Initial carbon contents of sample % :	Proximate analysis :			Recovery % based on the original carbon %
					Fixed carbon %	Ash %	Volatile matter %	
- 35 + 65	Kerosene oil	0.395	7.2	18.4	68.0	27.9	4.1	86.2
		0.395	5.2	„	70.3	25.49	4.21	87.9
		0.395	3.0	„	75.6	20.10	4.30	87.5
	m-cresol	0.51	7.0	„	47.9	48.98	3.12	82.4
		„	5.0	„	50.8	45.98	3.22	80.0
		„	3.0	„	69.27	27.08	3.65	81.0
	Steam distilled pine oil	0.398	7.2	„	45.60	51.29	3.11	79.8
		„	5.4	„	52.90	43.80	3.30	80.1
		„	3.0	„	56.70	39.98	3.32	80.4
- 65 + 100	Kerosene oil	0.395	7.2	14.77	71.40	24.37	4.23	88.0
		„	5.4	„	76.7	18.99	4.31	91.0
		„	3.0	„	79.8	16.62	4.58	90.8
	m-cresol	0.51	7.0	„	54.6	42.02	3.38	80.7
		„	5.2	„	62.7	33.65	3.65	82.4
		„	3.2	„	70.0	25.90	4.10	86.4
	Steam distilled pine oil	0.398	7.2	„	51.6	45.13	3.27	73.5
		„	5.0	„	57.4	39.26	3.34	79.3
		„	3.2	„	67.4	28.88	3.72	81.7

It may be observed that kerosene oil as the flotation agent gives the highest yield. With the coarser crude-35 and + 65 mesh the concentrated sample had 68% fixed carbon. However, with the -65 and + 100 mesh crude with the same flotation agent, the concentrated sample gave slightly higher value for fixed carbon i. e. 71.4%. The same increase in fixed carbon content was observed with the other two flotation reagents viz., m-cresol and pine oil. It may be concluded in flotation, the sizes -65 and + 100 mesh are more suitable and give better values of the fixed carbon even though the original crude powder contained less fixed carbon percent than the coarser crude powder.

It has been observed by B. W. Gandrud and G. D. Coe et al¹, that recovery of the valuable mineral in flotation varied with the pH of the pulp also. This was shown during flotation trials with a very low grade Alabama graphite ore. In the present investigations also three different pH values were used for the pulp and the percentage of fixed carbon in the concentrate is given in Table -V.

It may be observed that acidic pH values of pulp gave better yields on concentration by flotation and the lowest yields were obtained at the neutral pH. Here also it may be observed that percentage of fixed carbon in the concentrate is higher for the different pH values with the finer crude -65 and + 100 mesh powder as the starting material, than with the coarser crude -35 and + 60 mesh.

Kerosene oil gave the highest yields being 75.6% fixed carbon for -35 and + 65 mesh crude at pH 3 and 79.8% fixed carbon for -65 and + 100 mesh crude at the same pH. The recovery percentage was also the highest with kerosene oil. 86.2 to 87.9% of the valuable mineral was recovered with kerosene oil from coarser crude -35 and + 65 mesh powder. 88 to 91% of the valuable mineral was recovered with the finer crude -65 and + 100 mesh graphite powdered ore. It was also observed that a pH of 5 to 5.4 gave the highest recovery whereas the highest value for fixed carbon in the concentrate was given by the lowest pH 3 used in the flotation trials. Amount of kerosene added to the pulp was 0.4% by weight based on the weight of ore.

It was found that no appreciable concentration will be made with the lesser amounts of kerosene. However, kerosene being much less costlier than other flotation agents, it will still be economical to use about 0.4% or about 8.96 lbs. of kerosene per ton of ore. In continuous flotation methods, it may be possible to reduce appreciably the amount of kerosene used.

Further in a second stage flotation also kerosene was used as the flotation agent and the concentration was tried with three different pH values for the pulp. The values for the percentage of fixed carbon in the concentrate and percentage recovery in each case is given in Table VI.

TABLE—VI

Size of sample :	Frothing agent :	Quantity lb./cwt. of ore.	pH value of pulp :	Carbon % in the concentrate :	Recovery based on initial carbon content % :
— 35 + 65 mesh.	Kerosene oil	0.395	7.2	76.0	87.5
	"	"	5.6	76.8	88.1
	"	"	3.2	79.2	88.9
— 65 + 100 mesh.	Kerosene oil	0.395	7.0	79.1	91.2
	"	"	5.0	82.4	93.4
	"	"	3.2	85.2	91.3

It may be seen that a pH of 5 gives the highest recovery of 93.4%. However, the percentage of fixed carbon in the concentrate is highest with pH 3.2 being 85.2% and for pH 5, fixed carbon in concentrate is 82.4%. In the II stage flotation also, the finer graphite ore power — 65 and + 100 mesh gives higher recovery.

CONCLUSION

Graphite deposits occur as disseminated flakes in schist in a village, "Poovanthi" in Madurai Taluk. Fixed carbon content of this ore is 22.4%. Flotation concentration methods were used to concentrate the carbon content. Kerosene, pine oil and m-cresol were used as flotation agents. Of these, kerosene gave better yields with fixed carbon on the concentrate.

Two sizes namely $-35 + 65$ mesh and $-65 + 100$ mesh were chosen for flotation trials. The finer size $-65 + 100$ mesh was found more suitable for flotation. Here also kerosene gave the highest yields with 71.4 % fixed carbon in the concentrate obtained from the first flotation. Further trials were conducted by regulating the pH of the pulp and it was found that at lower pH values of the pulp, the yield was comparatively high, giving about 85.2 % fixed carbon at a pH of 3.2, in the second stage flotation trial with kerosene as the flotation agent. This graphitic carbon is comparable with high quality graphite that will be acceptable for commercial use. The authors hope that in view of the shortage in good quality graphite resources in India, the present investigation will assist in the successful utilization of low grade graphite deposits.

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Magnetic Susceptibility of Alkali Metals: Sodium and Potassium

BY

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1. INTRODUCTION

The study of the magnetic susceptibility of the alkali metals has assumed great interest in recent years because of the theoretical importance attached to such measurements from the point of view of the weak spin paramagnetism of the conduction electrons in metals.

The first comprehensive investigation of the magnetic susceptibilities of metals was carried out by Honda¹ and this was followed by another long series of thermomagnetic studies of metals over a wide range of temperature by Owen². Sucksmith³ studied the susceptibilities of the alkali metals, except lithium, over a range of temperature extending from 0°C to 500°C, using the Curie method. His results point out a gradual increase of susceptibility up to the melting point followed by a sudden fall when fusion takes place and then again gradually increasing with temperature. McLennan, Ruedy and Cohen⁴ using the Gouy method determined the susceptibilities of Na, K, Rb and Cs both at liquid air and room temperatures and found that the susceptibilities remain the same at both the temperatures. This leads to the conclusion that the alkali metals are anomalous paramagnetics showing no change of susceptibility within the temperature range employed. Lanc⁵ in a series of experiments investigated the alkali metals Na, K, Rb and Cs using the Gouy method. The elements used were prepared by successive distillations and were found to be absolutely free from ferromagnetic impurities.

The results so far obtained regarding sodium and potassium are given in Table 3. It may easily be seen that the results obtained by the various authors do show a large divergence, especially in the case of potassium.

2. THEORETICAL CONSIDERATIONS

The experimental values for the metals by the various workers form the basis for the development of the various theories put forward. The gram atomic susceptibility is given by

$$\chi_A = (\chi_A)_i + (\chi_A)_e$$

where χ_A is the gram atomic susceptibility, $(\chi_A)_i$ is the susceptibility of the quasi-independent metallic ion and $(\chi_A)_e$ the susceptibility of the free electrons. It was Langevin⁶ who first theoretically calculated the value of $(\chi_A)_i$ for systems with spherically symmetrical charge distribution, using the expression

$$(\chi_A)_i = -\frac{e^2 L}{6mc^2} \sum \bar{\gamma}^2 = -2.83 \times 10^{10} \sum \bar{\gamma}^2$$

where L is the Avagadro number and $\sum \bar{\gamma}^2$ is the sum of the mean square radii for each of the extra nuclear electrons.

With the introduction of quantum mechanics, different methods of calculating $\sum \bar{\gamma}^2$ have been suggested. Pauling⁷ was the first to compute this value. Hartree⁸ and Stoner⁹ made use of the distribution of electron density in a spherically symmetrical atom or ion. Slater¹⁰ gave rules for the calculation of $\bar{\gamma}^2$ for each electron. Brindley¹¹ calculated the susceptibility of various ions making use of Slater's method. Angus¹² modified Slater's computations by treating the 's' and 'p' electrons as separate groups.

Pauli¹³ and Frenkel¹⁴ applied Fermi-Dirac Statistics to the electron gas in a metal in the completely degenerate state for the evaluation of the gram atomic susceptibility $(\chi_A)_e$ of the free electrons. Pauli has deduced the formula

$$\chi_o = 2.209 \times 10^{-14} n^{1/3}$$

for the susceptibility of alkali elements near 0° K, n being the number of metal atoms per unit volume. He has shown that the alkali metals should

all be paramagnetic and that variation of susceptibility with temperature in those elements should be negligible. Pauli's formula neglects two factors which should contribute to the total susceptibility viz., 1. The diamagnetic effect of the atom cores and 2. a possible diamagnetic induction effect of the free electrons. Bloch¹⁵ suggested that $(\chi_A)_e 10^6 = 48.17q/\nu_0$ where q is the number of free electrons per atom and ν_0 is the width in volts of the energy band occupied by the electrons in the completely degenerate state. Landau¹⁶ showed that the curvature of the paths of the free electrons in a magnetic field would give rise to a diamagnetic susceptibility numerically equal to one third of the above paramagnetic susceptibility. This gives for the total susceptibility of the free electrons

$$(\chi_A)_e 10^6 = 32.11 q/\nu_0.$$

For perfectly free electrons the energy band ν_0 will be of the order of a few volts.¹⁷ Landau¹⁸ has also shown that the diamagnetic contribution by the conduction electrons is expressed by

$$\chi_L = 0.623 n_0^{1/3} \rho^{-2/3} A^{-1/3} 10^{-6}$$

where χ_L is the mass susceptibility, n_0 the number of free electrons per atom, ρ the density and A the atomic weight. Since the free electrons give a para-magnetic effect due to electron spin which is just three times as great as the Landau diamagnetism, the net paramagnetic contribution of these free electrons is given by

$$2 \chi_L = 1.246 n_0^{1/3} \rho^{-2/3} A^{-1/3} 10^{-6}.$$

For a metal therefore

$$\chi_A = (\chi_A)_i + 2\chi_L.$$

More recently Sampson and Seitz¹⁹ computed the magnetic susceptibilities of Li and Na from the stand point of the following four stages of approximations.

1. Paramagnetism of valence electrons neglecting the influence of exchange and correlation energy ;

2. Paramagnetism of valence electrons including exchange and correlation effects ;

3. Inclusion of diamagnetism of valence electrons on the basis of the Landau-Peierls Wilson theory ;

4. Inclusion of ion core diamagnetism.

Their treatment was on the basis of (1) Wigner correlation energy formula in calculating the spin paramagnetism and (2) the Landau's value for the diamagnetic susceptibility. They thus obtained for the volume susceptibility of sodium a value of 0.70 taking into account the spin paramagnetism, free electron diamagnetism and innercore diamagnetism. March and Donovan²⁰ while accepting the calculation of the spin paramagnetism by the use of Wigner's correlation energy formula suggest a correction factor for χ_{Landau} for the diamagnetic contribution of the free electrons for each of the alkali metals. The susceptibilities of Na and K calculated from theoretical methods are also given in table³.

It is well known that when a change of state occurs, the physical properties like sp. heat, thermal conductivity, electrical conductivity etc., also slightly but definitely change. It has been shown in several cases the magnetic susceptibility also changes. Sucksmith has recorded that between 0°C and 500°C the magnetic susceptibility of the alkali metals increases with temperature both in solid and liquid state. But later workers could not observe any change in susceptibility from liquid air temperature upto near the melting point of the substance. Thus it can be seen that there is no agreement among the results obtained by the earlier workers regarding the variation of susceptibility with temperature.

From what has been stated in the preceding paragraphs, it can be seen that there is a large disparity in the susceptibility values obtained by the various investigators and the lack of agreement between the theoretical and observed values and also the divergent nature of the results regarding the rate of variation of the susceptibility of the metals between the room temperature and the melting point. Hence it is found desirable to undertake a systematic and thorough study of the alkali metals with special reference to the solid and molten states and the temperature variation from room temperature to near about their melting points. Also the determination

of the susceptibilities of the alloys of the alkali metals should prove to be of interest as these substances, except lithium, are not supposed to be crystalline at ordinary temperatures. Accordingly, detailed investigations of the alkali metals have been taken up and some of the results obtained for sodium and potassium are reported here.

3. EXPERIMENTAL

Preparation of the bulbs

The metals first chosen for this investigation were sodium and potassium. The sodium was of the A. R. purity from Powers-Weightman-Rosengarten Corporation, Philadelphia. This was kept in an oil medium in the form of long rectangular blocks. A short length of the metal bar was cut and first rinsed in petroleum ether to remove the traces of oil sticking to its surface. The sodium with clean surface was then kept immersed in a shallow wide trough of petroleum ether which was previously distilled over sodium and maintained sodium dry with some sodium wire in it. It was necessary to take a small quantity of sodium in small spherical bulb for the following investigations. For this, a pyrex glass tube of about 8 m.m. in diameter was taken and blown to the shape shown in Fig. 1. The tube which

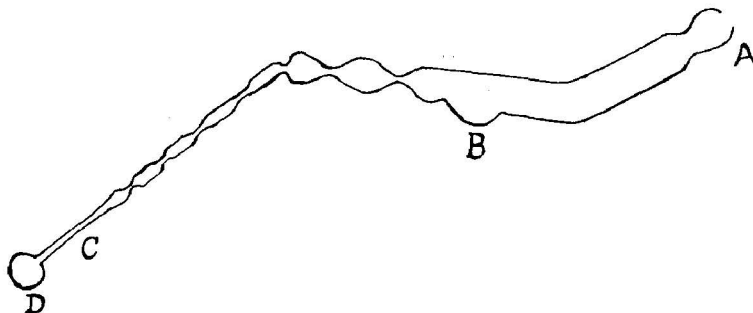


Fig. 1

was cleaned and kept dry was first filled with petroleum ether and kept immersed in the trough. Keeping the sodium well under the ether in the trough, the thin oxide layer over the sodium was scraped out and from the inner core a small piece of sodium was cut. This piece was inserted into the bulb B with a clean glass rod taking care not to expose the metal to air. The excess ether in the tube above the bulb B was drained and the tube was connected to a pump system by means of a short pressure tubing.

The pump system was made up of two stages, one containing a Cenco Hyvac pump with towers to absorb moisture and vapours and a high vacuum outfit. The latter was an all glass equipment consisting of a Waran pump backed by a Cenco hyvac pump, a McLeod gauge and a trap containing fused cocoanut charcoal immersed in a mixture of CO_2 snow and ether in a thermosflask. This was capable of giving a pressure of the order of 10^{-4} cms of mercury.

The ether in the tube ABCD was driven out by slow evaporation by working the first Cenco pump and when the tube became dry it was switched on to the high vacuum side and the pressure reduced to the minimum. The tube was then kept immersed in an ester bath upto bulb B and the bath was maintained at a temperature of about 150°C . The sodium was in molten state in the bulb B and at this condition the pumps were allowed to run for about half an hour to remove all occluded gases. The tube was then isolated from the pump by a stopcock. It was removed from the bath and a gentle horizontal jerk given to it. This enabled the molten sodium to flow over the constrictions leaving the small oxide layer partly in the bulb B and partly in the constrictions. By careful manipulation the bulb D was filled with Na in a pure condition with silvery metallic lustre. The bulb was then sealed off at the point C and the sealed end was drawn in the form of a hook. The same process was adopted for potassium also. The potassium used was of Kahlbaum A. R. purity.

Determination of Magnetic Susceptibility :

The magnetic susceptibilities were determined by the Curie method²¹ using a large electromagnet of Pye type. With the aid of a standard bulb, its position in the non-uniform field along a line of symmetry, where the Curie force was maximum was previously determined by observing the deflection of a spot of light on a scale. The field intensity for various field currents at the region of maximum Curie force was determined by using a search coil and a ballistic galvanometer which in turn was calibrated by a Hibbert's magnetic standard.

The retorsion method was adopted, the bulb containing the metal under investigation being brought with the help of the torsion head to the region of maximum Curie force when the field was on. This was done by bringing the spot of light to the right position within one centimetre in the region corresponding to the maximum Curie force. The standard substance used was double distilled water whose specific susceptibility was taken as -0.72^* at 30°C .

After finding the deflection corresponding to the bulb containing the metal, the bulb was weighed by a Paul Bunge type Chemical balance correct to $\cdot 1$ of a milligram. It was then broken at the stem and the metal in it was dissolved in alcohol. The bulb and stem were cleaned in boiling dilute HCl and water, dried in an air oven and weighed. The broken stem was fused to the bulb and the deflection for the empty bulb was found as before. From these the deflections due to the metal alone was obtained.

If d_s and d_w be the deflections obtained for the substance and water respectively then it may be shown

$$\frac{d_s}{d_w} = \frac{m_s \chi_s - k_a v_i}{m_w \chi_w - k_a v_i^1},$$

where m_s , m_w and χ_s , χ_w are the masses and specific susceptibilities of the substance and water respectively, k_a the volume susceptibility of the surrounding air and v_i and v_i^1 the internal volumes of the bulbs containing the metal and water. Neglecting the effect due to air, the above equation reduces to

$$\begin{aligned} \frac{d_s}{d_w} &= \frac{m_s \chi_s}{m_w \chi_w} \\ \chi_s &= \frac{m_w}{d_w} \cdot \frac{d_s}{m_s} \cdot \chi_w. \end{aligned}$$

Correction for Ferromagnetic Impurities :

It is well known that the presence of small traces of ferromagnetic impurities will to a large extent affect the magnetic susceptibility of the

* All susceptibility values in this paper are given in 10^{-6} units.

substances. Honda has shown that although, we may accurately determine the iron content of a substance by chemical analysis, we cannot, from data so obtained, determine the effect of the iron on the magnetic susceptibility of the element. The total amount of iron present may not be free, but partly or entirely combined in a nonmagnetic form. The correction due to the iron content may best be determined by a method due to and used by Owen. If the specific susceptibility be determined for different fields, the results can be represented by

$$\chi_i = \chi_p + \frac{\sigma m}{H}$$

where χ_p and χ_i represent the susceptibilities of the pure and the impure substance, σ the specific intensity of magnetisation of the impurity, m the mass of the impurity in unit mass of the substance and H the field intensity. Estimated in this way, Owen found the amount of free iron to be considerably less than the total iron content as determined by chemical analysis.

If the specific susceptibility is constant at different field strengths, then $\chi_p = \chi_i$ and there is no impurity. If, however, χ_i varies with H , it necessarily indicates a small iron impurity. In such cases a graph is drawn between χ_i and $\frac{1}{H}$ and the points plot themselves along a straight line. By producing this line to meet the Y axis, the value of χ corresponding to infinite field strength or $\frac{1}{H} = 0$ is found. This extrapolated value gives χ_p .

In this investigation all the bulbs containing sodium and potassium were studied at different field strengths corresponding to field currents 3, 4, 5 and 6 amperes. From these readings graphs were drawn and χ_p extrapolated.

Temperature Variation:

The melting point of sodium is 97°C and that of potassium is 62.3°C. The range of temperature used in the present work was from 30° to 120°C. The heater was made by winding a thin wire of manganin in a non-inductive way over a narrow cylinder prepared out of a copper sheet, asbestospaper

being used for insulation. A test experiment showed that there was no detectable change in the field inside the heater, when fixed in between the pole faces and a heating current sent through it. The pole faces were covered by asbestos paper and a thin layer of cotton wool and a small air gap was maintained between the heater and the pole faces. The temperatures were measured by a calibrated thermocouple. Three sodium bulbs and three potassium bulbs were subjected to temperature changes. For each of these bulbs readings were taken for different field strengths at every temperature and the value of χ was found by extrapolation.

4. RESULTS

The field strengths at the region of maximum Curie force for various currents as determined by the use of a search coil and a ballistic galvanometer are given in Table I

Table -I

Current in amperes	Field H in Kilo gauss	1/H
2	2.87	.348
3	4.12	.243
4	4.99	.201
5	5.54	.181
6	5.74	.174

Susceptibility values were determined at the room temperature using 12 bulbs for sodium and 10 for potassium and the results obtained for 5 bulbs in each case are given in table 2 as representative sets.

Table—2

Bulb No.	Current in amps.	SODIUM			POTASSIUM		
		Mass in gms	Specific susceptibility	Extrapolated	Mass in gms.	Specific susceptibility	Extrapolated
1	6	·067	·603	·575	·0575	·448	·450
	5		·610			·454	
	4		·609			·458	
	3		·620			·460	
2	6	·0532	·602	·580	·1228	·438	·440
	5		·605			·442	
	4		·607			·442	
	3		·611			·443	
3	6	·0963	·574	·580	·0844	·475	·460
	5		·580			·477	
	4		·581			·479	
	3		·575			·475	
4	6	·0852	·565	·570	·0743	·469	·455
	5		·569			·477	
	4		·571			·476	
	3		·570			·482	
5	6	·1064	·565	·570	·0517	·458	·455
	5		·570			·461	
	4		·570			·464	
	3		·572			·461	

Fig. 2 shows the graphs where χ is plotted against $1/H$ for one Na bulb and one K bulb. It could be seen that the points plot themselves on straight lines nearly parallel to the horizontal axis showing that the specimens used were fairly free from iron impurity. From such graphs the values of χ_p were extrapolated for both metals. By this method the mean susceptibility for sodium was found to be 0·575 which is the mean

of twelve values. The mean susceptibility of 10 values obtained for potassium is found to be 0.455.

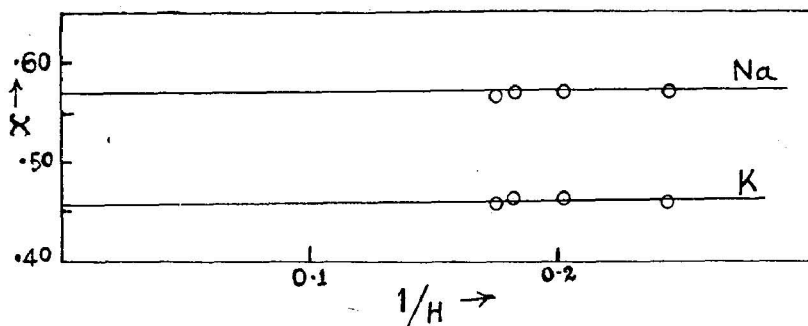


FIG 2

Table 3 gives the values of the specific susceptibility obtained by various authors up till now for sodium and potassium as compared with the values obtained in the present investigation. It could easily be seen from the table that our values very closely agree with those of Sucksmith and McLennan for Na and with that of McLennan for potassium.

Table—3

	Honda	Owen	Bernini ^{2,2}	Sucksmith	McLennan Ruedy and Cohen	Lane	Rao. ^{2,3}	Present authors	Theoretical		
									Sampson and Seitz	Pauli	Bitter ^{2,4}
Na	·51	·50	·54	·59	·59	·65	·60	·575	0.70	·68	·22
K	·40	·63 ·58	·63	·51	·45	·54	·52	·455	—	·59	·17

As previously stated three sodium bulbs and three potassium bulbs were subjected to temperature variation near their melting points. In tables 4 and 5 are given the results obtained for two sodium bulbs and for two potassium bulbs. The extrapolated values for the two metals for each temperature were found from graphs drawn between χ and $1/H$.

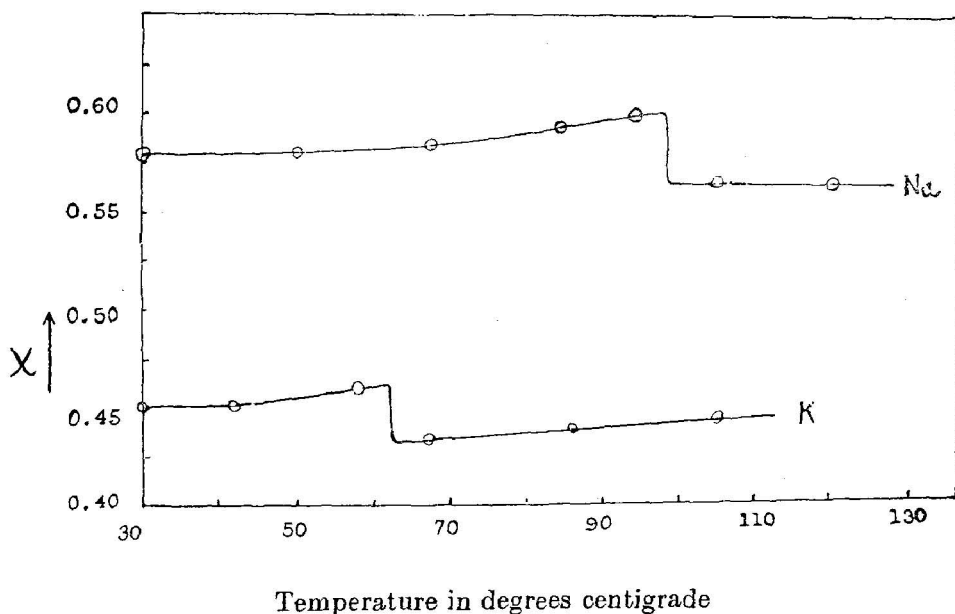
Table—4 •

Temperature° C	Current in amps.	SODIUM BULBS.			
		Bulb I		Bulb II	
		•X	X extrapolated	X•	X extrapolated
30	6	•603		•602	
	5	•610		•610	
	4	•609		•612	
	3	•620	•575	•611	•580
50	6	•590		•505	
	5	•602		•602	
	4	•607		•613	
	3	•613	•575	•610	•580
67	6	•595		•618	
	5	•603		•619	
	4	•603		•629	
	3	•607	•580	•639	•585
84	6	•595		•610	
	5	•598		•620	
	4	•596		•615	
	3	•597	•590	•618	•595
94	6			•615	
	5			•619	
	4			•624	
	3			•630	•600
105	6	•595		•571	
	5	•590		•574	
	4	•601		•570	
	3	•606	•560	•602	•565
120	6	•579		•580	
	5	•579		•574	
	4	•590		•588	
	3	•594	•560	•602	•565

• Table—5

Temperature °C	Current in amps.	Potassium Bulbs			
		Bulb I		Bulb II	
		X	X extrapolated	X	X extrapolated
30	6	·467		·450	
	5	·475		·455	
	4	·476		·447	
	3	·484	·450	·453	·450
42	6	·468		·445	
	5	·469		·451	
	4	·469		·450	
	3	·476	·450	·448	·450
58	6	·469		·459	
	5	·475		·458	
	4	·476		·460	
	3	·476	·460	·465	·460
67	6	·456		·435	
	5	·460		·436	
	4	·460		·440	
	3	·458	·435	·438	·435
86	6	·469		·438	
	5	·477		·439	
	4	·479		·444	
	3	·484	·435	·444	·435
105	6	·464		·435	
	5	·462		·440	
	4	·468		·440	
	3	·467	·440	·440	·440

In Fig. 3 is shown graphically the temperature variation of the specific susceptibility of sodium and potassium from room temperature to about 120°C in each case. The results obtained in both the cases show a slight but definite increase in susceptibilities as the melting point is approached. As fusion takes place the value falls down abruptly by a small amount. In the case of potassium a very slight increase in susceptibility is observed as temperature is increased beyond the melting point. These observations are in general agreement with the results obtained by Sucksmith for sodium and potassium.



5. DISCUSSION

The atomic weight of sodium is 22.99 and that of potassium is 39.09. Hence the gram atomic susceptibility for sodium has the value 13.22 and that of potassium is equal to 17.78. The ionic susceptibilities of Na^+ and K^+ , as calculated from the measurements of Flordal and Frivold²⁵, are -6.9 and -15 respectively. Hence the contribution to

the susceptibility $(\chi_A)_e$ of a gram atom of sodium by the valence electron works out to be 20.12 and $(\chi_A)_e$ for potassium is 32.78. From the equation

$$(\chi_A)_e = 32.11 q / \nu_0$$

where q , the number of valence electron is one for the atoms in question, we can deduce the value for ν_0 the width of the energy band in volts for the free electrons. In table (6) the values of ν_0 for Na and K are given and the calculated energy band width in volts are also given for comparison.

Table—6

Element	(χ_A)	$(\chi_A)_i$	$(\chi_A)_e$	ν_0	Calculated energy band width in volts.
Na	13.22	-6.9	20.12	1.59	3.16
K	17.78	-15.0	32.78	0.98	2.06

The values in the last two columns indicate a narrowing of the energy band as suggested by Stoner²⁶.

The temperature variation of the susceptibility of the alkali elements has been considered by Stoner²⁷. He has pointed out that, for the alkali metals the conditions approach most closely those for which the free electron calculations should apply. He has suggested that the increase of susceptibility for the alkali elements should be mainly due to the change in the value of ν_0 due to thermal expansion. According to his calculations

$$\nu_0 \propto n_v^{-2/3}$$

where n_v is the number of ions per unit volume. If α_v represents the coefficient of cubical expansion and T the absolute temperature then,

$$(\chi_A)_e \propto \frac{1}{\nu_0} \propto n_v^{-2/3} \propto 1 + \frac{2}{3} \alpha_v T$$

Hence,

$$\Delta (\chi_A)_e / (\chi_A)_e \Delta T = \frac{2}{3} \alpha_v$$

This expression states that the temperature coefficient of the paramagnetic contribution of the free electrons is found to be nearly equal to two thirds the coefficient of cubical expansion. Using our values, the temperature

coefficient of paramagnetic contribution of the free electrons is calculated for the solid state as follows. From Table 4 the susceptibility of sodium is 0.580 at 30° and 0.600 at 94° C. The paramagnetic contribution of the free electrons in a gram atom works out to 20.24 at 30° and 20.7 at 94° C and $\Delta(\chi_A)_e / (\chi_A)_e \Delta T$ is found to be 3.55×10^{-4} . Similarly calculations are made for potassium using our values from table 5 and the results for sodium and potassium so obtained are given in table 7

Table—7

	$(\chi_A)_e$	$\frac{\Delta(\chi_A)_e}{\Delta T}$	$\frac{\Delta(\chi_A)_e}{(\chi_A)_e \Delta T}$	$\frac{2}{3} \mathcal{L}_e$
Na	20.24	7.19×10^{-3}	3.55×10^{-4}	1.8×10^{-4}
K	32.59	7.11×10^{-3}	4.38×10^{-4}	1.9×10^{-4}

It could be seen that our values $\Delta(\chi_A)_e / (\chi_A)_e \Delta T$ are of the same order of magnitude as the values of $\frac{2}{3} \mathcal{L}_e$ taken from I. C. T. thus lending support to Stoner's calculation and conclusions.

Further investigations regarding the susceptibility measurements of the other alkali metals and the alloys of the various alkali elements and their variation with temperature are in progress and fuller discussion will be given later.

6. SUMMARY

The specific magnetic susceptibilities of sodium and potassium have been determined by the Curie method at different temperatures ranging from 30° to 120° C to study the variation of the susceptibility near about their respective melting points. The specific susceptibility values of sodium and potassium are found to be 0.575×10^{-6} and 0.455×10^{-6} respectively at 30° C and the value for Na is in agreement with those obtained by Sucksmith and McLennan, Ruedy and Cohen, and the value of K with that obtained by the latter authors. It is observed that the susceptibility in the case of both the alkali metals increases slightly up to the melting point and suddenly decreases when fusion takes place. The

variation of the susceptibility contribution of the valence electron with increase of temperature is in general agreement with the theory of Stoner and the experimental results obtained by Sucksmith.

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Water Supply in The Madras City.*

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SOURCE.

THE subject of supplying the Madras City with an abundance of pure drinking water had engaged the attention of the Government for many years prior to 1866 during which year a definite action was taken on the numerous reports and suggestions submitted by professional engineers and others. Till about this period the city obtained its drinking water supply solely from shallow wells and tanks which were subjected to serious pollution owing to the porous nature of the soil on which the city was built. Putrifying organic matter found easy access to the water-bearing strata during times of monsoons and thus caused pollution.

Of the various proposals put forward for giving the residents of Madras a copious supply of water, the Government adopted the proposal of Mr. Fraser to tap the river Cortalayar. By placing a low masonry weir across the river at a place known as Tamarapakkam about 17 miles to the north-east of the city, the waters of the river were diverted and led first to Cholvaram lake and thence to Red Hills Lake by means of two channels known as the Upper and the Lower Supply channels respectively. Both these lakes also receive considerable supply of water from their own catchment areas.

The works connected with the diversion of water from the Cortalayar river into the two tanks were undertaken by the Government as a combined water supply and irrigation project and completed in 1870. A suggestion of the Government that the Madras Corporation may become joint owners of the scheme by contributing 50 per cent of the cost was not however accepted by the latter who chose to remain as a mere consumer paying for the water drawn from the lake for the city's use. The cost of the works was therefore entirely met by the Provincial and Central Governments and their maintenance is in the hands of the Government Public Works Department.

* Extension Lecture delivered at the Annamalai University in 1953—54.

Madras draws its water supply directly from the Red Hills Lake through an intake tower known as the Jones Tower situated at the deepest part of the lake. The water thus drawn is let into roughing filters where it is made to pass through a gravel bund which helps to relieve the raw water of the grosser impurities. Fortunately, owing to the fact that the river water is impounded in the two lakes in succession, it goes through an effective process of sedimentation and the water is usually clear when it is drawn through the intake tower for the city's use. The water thus screened through the roughing filter is led through two masonry covered conduits upto the Kilpauk Water Works where it enters a series of slow sand filters. Water filtered through these slow sand filters is sterilised by chlorination and stored in under-ground storage tanks and then pumped into the city distribution system by means of electrical and steam driven pumps. All these works were carried out by the Madras Corporation and are maintained by them.

The Red Hills Lake is situated about 8 miles to the northwest of Madras on the Great Northern Trunk Road. The water from this lake and the Cholavaram lake further north is also used to irrigate about 7,500 acres of wet lands. The total quantity of water issued from the Red Hills Lake for the city supply in a normal year will be about 8,750 million gallons or 1,400 million cubic feet. The quantity of water used for irrigation will be about 340 million cubic feet per annum. The total estimated quantity lost by evaporation in the two lakes is about 1,100 million cubic feet per annum. The Corporation pays to the Government for all water drawn from the Red Hills lake for the city supply at Re. 1/- per 1,000 cubic yards, subject to a maximum payment of Rs. 56,000 per annum, the quantity of water drawn being measured by a weir recording apparatus installed at the Roughing Filters at Red Hills.

On account of the developments that have taken place in the city during the last 50 years and the large increase in the city population, the Corporation began to feel by about 1936 the urgent need for an additional source of water supply for the city. The storage at Red Hills was found only just sufficient to meet the city requirements for one year and the failure of the northeast monsoon in 1938 placed Madras in desperate straits.

To meet the increased demand for water for the growing needs of the city it was therefore found necessary to augment the source of supply. After investigating various possibilities, it was decided in 1940 to construct a dam across the Cortalayar river and form a Reservoir at Poondi, 12 miles above Tamarapakkam Anicut. This reservoir is for impounding the greater flood discharges which normally surplussed over the Tamarapakkam and Vallur anicuts and wasted into the sea. The reservoir is designed to impound 2,500 million cubic feet of water (the full reservoir level being 137 feet) and has a water spread of nearly $12\frac{1}{2}$ square miles. Its storage capacity will be nearly equal to the combined storage capacity of the Cholavaram and Red Hills lakes.

The water impounded at the Poondi Reservoir is drawn into the Red Hills lake through the Cortalayar river upto Tamarapakkam anicut and from there through the Upper and Lower Supply channels. The additional storage of water thus made available at Poondi has helped to a great extent in averting the threatened water famine in the city due to the successive failures of the north-east monsoon during 1947 to 1952.

The Poondi Reservoir has subsequently been renamed Satyamurthi Sagar.

CONVEYANCE OF WATER

Till 1914, water from the Red Hills lake was drawn through an open channel upto Kilpauk and it was directly let into the distribution system without any sort of filtration or pumping, sedimentation by storage at Red Hills lake being considered sufficient safeguard for ensuring a pure supply of water. This method, although a decided improvement over the polluted water supply from wells and tanks on which the city depended prior to 1870, had very many disadvantages. As the open channel leading from Red Hills to Kilpauk was subject to pollution, a covered masonry conduit with a maximum carrying capacity of 23 million gallons of water per day (up to the springing level of the arch) was constructed to lead the water from the Roughing Filters, at Red Hills to the newly constructed Water Works at Kilpauk for a distance of about $7\frac{1}{2}$ miles. The alignment of the conduit was continuous to the open water supply channel for its entire

length from Red Hills to Kilpauk. The conduit is rectangular in shape, 5 feet wide with vertical side walls 4 feet high to the springing of the arched roof which has a height of 18 inches. The floor is inverted with a dip in the centre of 3" so that the maximum height is 5'-9". The flow is gravitational with an average gradient of 1 in 4470. The conduit is provided with manholes fitted with air inlets or outlets alternately at about every furlong. As this conduit has been found insufficient to meet the growing demand of the city, a second rectangular masonry conduit 6' 6" x 4' with an arched roof and with a maximum carrying capacity of 32 million gallons of water per day has now been constructed at a cost of about Rs. 56 lakhs and brought into use from 26th October 1949.

FILTRATION.

At the Kilpauk Water Works there are 17 slow sand filters fourteen of which measure 200' x 100' and the remaining three 200' x 130' each.

The filtering materials of these filters consist at present of 6" fine sand supported on 2 inches of coarse sand which rest on a 2 inch layer of 3/8 inch stone which again rests on another 2 inch layer of 3/4" stone. Below these are the loose brick collecting cross drains leading to a central longitudinal drain which is sunk below the floor of the filters. The raw water before it enters the filters is chlorinated and then it percolates through the above filtering media, runs down the central longitudinal drain and comes out into a rectangular chamber which contains an automatic outlet regulator. The average rate of filtration is about 8" vertical per hour. The filtrate from all the above filters is led into four underground storage tanks altogether capable of storing 6½ million gallons. These tanks are to provide adequate storage to serve as a balance between the rate of filtration and the rate of pumping water to the City. The four filtered water tanks are independent of each other so that each one of them can be isolated for cleaning without interfering with the working of the others. All the filtered water is chlorinated just before it enters the filtered water tanks with an average dose of one part of chlorine per million parts of water. Chlorination has the effect of killing all harmful bacteria if they are to be found in the filtered water even after filtration.

From the filtered water tanks, water gravitates to the suction culvert leading to the pumps whence it is pumped into the City Distribution System through a 48" steel pumping main about half a mile long. A steel circular elevated tank of 104' in diameter 28' high with a capacity of 1½ million gallons is connected with the pumping main close to the pumps to act as a balancing tank between the pumps and the distribution system.

There are three pumping units run by steam and three electrical units at Kilpauk Pumping Station. The steam pumping plants installed in 1914 comprise of three high duty Worthington direct-acting pumping engines each capable of delivering 12,000 gallons of water per minute against a total head of 80 feet.

The three electrical units were installed (two in 1936 and one in 1950) to meet the increased quantity of pumping for the growing needs of the City. These electrical units are each capable of pumping 20,000 gallons per minute against a total head of 80 feet.

DISTRIBUTION SYSTEM

The City Distribution System consists of 29.5 miles of trunk mains and sub-mains varying in size from 48" diameter to 9" diameter nearly 365 miles of distributaries and street mains varying in size from 8" to 4" and a few lengths of 3" and 2½" street mains and riders. The four trunk mains which supply the several parts of the city branch off from the 48" steel pumping main which ends at the place known as the Kilpauk Shaft. At this place there are valves fitted on to each of the trunk mains to enable the pressure on the trunk mains being regulated suitably at different parts of the day.

There are nearly 54,000 private house connections given from the Corporation water mains in the city connected to the Red Hills supply, which have to be supervised and maintained by the Corporation. Sembiam has no private house connection, whereas in Saidapet there are 150 private house connections.

The work inside the private houses have to be done by plumber licensed by the Corporation while the portions of the house services which

are in the street limit have to be maintained by the Corporation at the cost of the respective owners or occupiers. Private house connections are allowed to all buildings which are separately assessed and which have an annual valuation of Rs. 60/- and above. Ordinarily two taps with a 3/4" service pipe are allowed without a meter for domestic houses. About 4,000 connections given for private houses and for industrial or trade purposes are metered connections.

In addition to the private house connections there are about 2,670 fire hydrants, 3,595 public fountains, 182 bathing fountains and 64 cattle troughs in the City.

There is a full time Water Analyst at the Filter Beds, Kilpauk, working under the direct supervision of the Health Officer who takes samples of water from the Filter Beds every day, and from the Distribution System at frequent intervals, and conducts a thorough bacteriological and chemical examination of the same. He supervises the chlorination of the city water-supply and regulates the dose of chlorine to be added to the water to sterilise it perfectly.

For the maintenance of the water supply system in the city, the Corporation levies water tax at $1\frac{1}{2}$ per cent of the annual value of all premises in the city and the total revenue derived in a year is Rs. 7 lakhs approximately. Besides this, the income derived by way of excess water charges from metered connections, and of supervision charges levied on the work of private house connections etc. works out to Rs. 11.5 lakhs approximately per annum. As against these revenues, the Corporation spends nearly Rs. 18 lakhs per annum on the maintenance of the water supply system in the city including the annuity for repayment of all loans taken for the execution of the various items of capital works.

Now coming to the aesthetics of a water supply : Aesthetics means generally the beautiful and the appreciation of that quality; and as applied to a water supply it means the qualities of clarity, pleasing taste and odourlessness. These are physical qualities and should be distinguished from bacteriological and chemical purity of a drinking water. It is not enough

if we have safe water to drink. The ordinary consumer in towns and cities cannot be expected to be satisfied with the bacteriological quality alone of drinking water. His aesthetic sense will have to be satisfied and the water will have to be pleasing in taste and appearance. None likes a colour however beautiful it may be in the drinking water and there is no doubt that in appearance it should be absolutely colourless. Regarding the taste, distilled water without any taste is at once ticked off as insipid which clearly shows that the consumer desires some taste in water; it should be pleasing to his palate.

These are therefore the physical qualities desired in a drinking water and they please the consumer in the same manner as good architecture in a structure pleases an onlooker. There are aesthetics in buildings, bridges and roads; and a bacteriologically safe water without the physical qualities mentioned above can be compared to a structure which is built safe and strong without any architectural qualities or a pleasing appearance.

In purifying a drinking water, the Water Engineer has two objects in view—the more important is the removal of any danger from pathogenic organisms and the other to improve its physical appearance. The latter object, while it ought to be subordinated to the former, often is not, and in the eyes of the consumer an unsavoury water will often cause more complaints than a pure sparkling water that may be polluted with disease organisms.

Clarity of water can be easily understood and it can be measured by the extent of visibility of any bright object when placed at various depths of a sample of water in a glass cylinder. Now the depth of visibility will depend on two factors — the nature of the source of supply and the method of filtration adopted. Turbidity or want of clarity in a raw water is generally caused by silt or clay in suspension, though living or dead algae or other organisms may also cause it. Thus it may be of inorganic or organic origin. An impound water such as that obtained for the Madras city supply from Red Hills and Cholavaram Reservoirs is generally not very turbid for obvious reasons, though there is considerable amount of seasonal variation in this factor. In this connection it is worth noting that

a low turbidity caused by silt or other inorganic substances may result in relatively high organic turbidity, the explanation being that the low inorganic turbidity permits sunlight to penetrate freely in the water in its impounded condition stimulating a heavier growth of algæ. The organic matter present in the Red Hills Reservoir is mostly colloidal in character and causes considerable difficulties in filtration.

In regard to the physical and chemical properties which render water disagreeable to taste or smell without producing a concrete harmful effect, a difficulty is encountered in that the degree of offensiveness is not accurately measurable, being largely dependent upon the individual tastes and habits. The quality of tastes and odours likely to be present in our waters also vary widely. Much can be said about tastes and odour in water, but let me confine myself to their origin only. Tastes and odours are usually those of natural origin and those caused by pollution of the water with the waste products of industries, sewage, etc. or sometimes by the slow sand filtration as in Madras.

Now, let us see how far the Madras water works were successful in supplying a water palatable and free from odour. For this purpose I must take you back to the slow sand filters when they were started in 1914. The original scheme of Mr. Madeley, the then Special Engineer to the Corporation of Madras, had provided for 21 filters 200' $\times$ 100' to be worked at the slow rate of 4" vertical per hour capable of filtering about 1 million gallons of water per filter per day. But only 14 of these were constructed for immediate use and were completed in 1914. Within a year of this, the filtration system broke down giving erratic results and producing sulphuretted hydrogen in the filtrate. The disagreeable smell of this gas made the water highly offensive and unpalatable. Without going into the historical side of how extensive investigations were made by Experts in Public Health and Government constituted Filtration Committees, I shall briefly examine the technical aspect of it and point out how this hydrogen sulphide was produced.

Hydrogen sulphide can be produced in two ways. In nature the sulphur bearing proteins in water are acted upon by putrefactive bacteria

producing sulphuretted hydrogen. Secondly, inorganic sulphates can also be reduced to hydrogen sulphide by a group of organisms known as sulphide fermenters. They are strictly anaerobic and thrive in the sand filters of Madras in the absence of oxygen. They act upon the sulphates taking the oxygen present in them in order to take carbon from the organic matter for their own sustenance. The resulting compound is hydrogen sulphide. This in turn acts on the iron in the sand and produces ferrous sulphide and the sand thus forms the store house of the black ferrous sulphide. At the same time, decomposition of organic matter is going on in the filtering skin and carbon dioxide and ammonia are produced. Carbon dioxide acts upon the black ferrous sulphide producing free hydrogen sulphide. As the filter skin gets older and older, more carbon dioxide is produced and consequently more hydrogen sulphide. The remaining ferrous sulphide is converted into sulphate by the action of the sun and atmospheric oxygen when the filter bed is exposed for overhauling and the sand washed and dried in the sun. The sulphate again starts the cycle of operations mentioned above.

In the winter months the output of hydrogen sulphide is very much less. The process of sulphate reduction takes place even in these months as evidenced by the formation of black iron sulphide in the sand, but hydrogen sulphide is not noticed in the filtrates in the same large quantities as in summer. This is due (1) to the small scale of decomposition of protein matter as a result of dilution of organic content in the lake and (2) to hydrogen sulphide being taken up by iron in the sand to form iron sulphide.

Thus palatability was lost and to get out of this precarious position, it was decided to reduce the thickness of the fine sand in the sand filters giving rise to a higher rate of filtration which avoided the anaerobic condition in the filters and thereby stopped the production of this obnoxious gas. Whereas with the full depth of 2 to 3 feet of fine sand the slow sand filters were able to produce a clearer purer water bacteriologically but with hydrogen sulphide and sulphur bacteria, under the altered conditions of the filters with about 6" of fine sand, the purity resulting from filtration was sacrificed as well as clarity of the filtrate. Sterilisation by chlorination was

thus made the first and last line of defence in the water supplied to the city which often remains hazy and yellowish having had the benefit of only an indifferent mode of filtration.

The Water Filtration Committee constituted by the Government to go into the question of purification of the Madras raw water after carrying out extensive experiments for the last many years on the various types of pre-treatment such as aeration with and without sedimentation, percolation filters as pre-filters to slow sand filters and various other possible methods came to the conclusion that nothing but chemical treatment of the water – in this case alum coagulation – followed by rapid sand filtration will suit the Red Hills water. The Committee also worked on the optimum values of alum dosage, hydrogen ion concentration etc. and recommended its results to the Corporation.

The second stage of improvement and expansion of the Madras Water Supply by the addition of the Satyamurthi Sagar at Poondi, the construction of a Second Conduit for bringing water from Red Hills to Kilpauk, the addition of an Electrically driven pump, and the various other works are either under execution now or under contemplation.

Knowing Madras Water Supply is knowing its troubles. In storage it is inadequate; in filtration it is imperfect and in distribution it is inequitable. The various measures taken for the improvement under each one of these have been explained and thus a large field covered.

It may not be given to many of us to design a water supply for a large city or carry out major improvements to it; for such opportunities come seldom. But a knowledge of the problems of a city water supply will stand you in good stead in designing even small water supplies to towns or villages.

When you are required to give a water supply to any community, its safety is in your hands, and it is a great responsibility. Polluted waters imperfectly dealt with will give rise to water-borne diseases like typhoid and cholera which even now take large toll of human life in Indian

towns and villages. Supply of a safe and adequate quantity is a crying need and it is of vital importance to civilised life.

CERTAIN PRELIMINARIES TO THE PREPARATION OF A WATER SUPPLY PROJECT FOR A CITY OR TOWN.

When an engineer is called upon to prepare a water supply scheme for any town of large or small magnitude, the reasons for making an enquiry in connection with the quantity of water available for supply to a city or town should be set out first in order to point out the scope of the work of investigation that is entrusted to the engineer.

The determining of the nature of treatment for a water supply will depend entirely on the quality of the raw water to be dealt with, and it is no use going into the various known methods of treatment on a hypothetical basis. The same can be said about its method of storage, and its distribution, which will also depend mostly if not entirely on the situation of the town with reference to the supply works, and the shape and layout of the town. The computation of the ultimate population for the design and the prospected supply per capita are the two essential factors which govern design.

Determining the total quantity of water required is the important factor in the preparation of a water supply scheme. The total quantity of water will depend on the total population to be served and the daily rate of supply per head contemplated. The needs of an average person with regard to supply will depend on the habits and customs of the community and the nature of sanitary installations to be introduced for a better and healthful living. Improvements in the direction of advanced methods of water carriage systems of sewage and sullage disposals from the dwelling place and domestic washing and culinary uses are quite called for when we think of a town or city which should improve into a modern one; but this should not be the sole criterion to determine the water needs of an individual. Availability of water is a great moderating factor and it is only after a due consideration of this that the daily supply per capita should be fixed. The second factor to be decided upon as mentioned above is the population for which the supply is going to be designed.

Population fundamentally should increase in geometrical progression when the birth exceeds death in a uniform ratio. Knowing the census figures for the few past decades it can be calculated from the simple formula

$$P = p \left(1 + \frac{r}{100} \right)^n$$

Where P = ultimate population.

p = present population.

r = rate of increase per decade, per cent.

n = number of decades in the interval.

But such conditions usually do not exist in practice and therefore we have to resort to methods of approximation to predict future population. The Curvilinear method using semi-logarithmic section paper is widely used. Capital expenditure is involved in the building of a water supply and that would mean loans which will have to be repaid yearly and on which interest will have to be paid. If the period of design is too large, the initial outlay will be too large and the present generation will be unnecessarily burdened with too large a payment, whereas if the period is too small, the initial outlay becomes useless within a short time when the water works will require expansion in a major way. All these must determine the period. 30 to 50 years is usually taken as the period of design of large water supply works.

It is here that I must again mention certain features of the Madras Water Works mainly designed in 1911-1914. Considering the population figures of 1871, 1881, 1891, 1901, and 1911 the Engineer derived a population of 6,66,000 in the City of Madras in the year 1961. The derivation looks quite reasonable, as you can see from the curves but the City's population far exceeded this speculation. Even in 1941 the figure came to 7,77,000 and today with the addition of a lakh in the newly extended areas, the population is a million and a half. Considering the inequitable supply of water in the city, a design of the distribution system on a Zonal basis is being worked out by me, but this will ultimately involve very large outlay and time. However a beginning is being made in the preparation of such a

scheme. Our future population for the designs that are being worked out now is being suggested at 30 lakhs in the year 2001. An impeachment of the present Engineer will be in the hands of the people of 2001 !

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ON A PROBLEM IN CURVE FITTING

By

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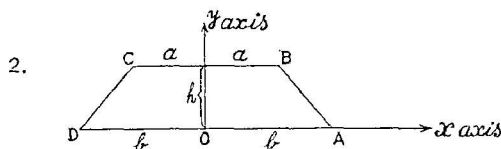
The Gram-Charlier expansion for a frequency function $f(x)$ seeks to exhibit the function in the form :

$$f(x) = \sum_{j=0}^{\infty} C_j H_j(x) \mathcal{L}(x) \dots \dots \dots (1)$$

where $\mathcal{L}(x) = (2\pi)^{-\frac{1}{2}} \exp(-\frac{1}{2}x^2)$ and $H_j(x)$ are the well known Hermite polynomials and C_j 's are certain constants¹. Such an expression provides in many cases very close approximations to the function even by taking the first few terms thereof and thus serves as a convenient tool in the problem of curve fitting. Following this method, we shall, in this note, demonstrate the closeness of fit by taking for the curve represented by the function $f(x)$ that made up of the line segments AB, BC, CD of the figure² where AB and CD are the slant sides and BC (= 2a) the shorter of the parallel sides of an isosceles trapezium ABCD in which the base AD (= 2b) lies along the x - axis.

Since the constants C_j 's in (1) involve the moments of the distribution with frequency function $f(x)$, we calculate the moments from the moment generating function $\phi(t)$ of $f(x)$ which is easily seen to be³.

1. vide Kendall, *Advanced Theory of Statistics*, Vol. I, page 147.



3. $f(x)$ is an even function in $-b \leq x \leq b$, defined, by : $f(x) = h$ for $0 \leq x \leq a$ and $f(x) = \frac{h}{b-a}(b-x)$ for $a \leq x \leq b$ with $f(-x) = f(x)$.

$$\phi(t) = \frac{2h}{b-a} \sum_{s=0}^{\infty} (-1)^s \frac{b^{2s+2} - a^{2s+2}}{(2s+2)!} t^{2s} \dots \dots \dots (2)$$

Thus the moments μ 's about the mean are given by :

$$\left. \begin{aligned} \mu_{2s} &= \frac{(2s)!}{(2s+2)!} \left(b^{2s+2} - a^{2s+2} \right) \frac{2h}{b-a} \\ \text{and } \mu_{2s+1} &= 0 \\ \text{for } s &= 0, 1, 2, 3, \dots \end{aligned} \right\} \dots \dots \dots (3)$$

Further from (1) and (3) we get :

$$f(x) = \sum_{s=0}^{\infty} C_{2s} H_{2s}(x) \mathcal{L}(x) \dots \dots \dots (4)$$

$$\text{where } C_{2s} = \frac{1}{(2s+2)!} \left\{ H_{2s+2}(b) - H_{2s+2}(a) \right\} \frac{2h}{b-a} \dots \dots \dots (5)$$

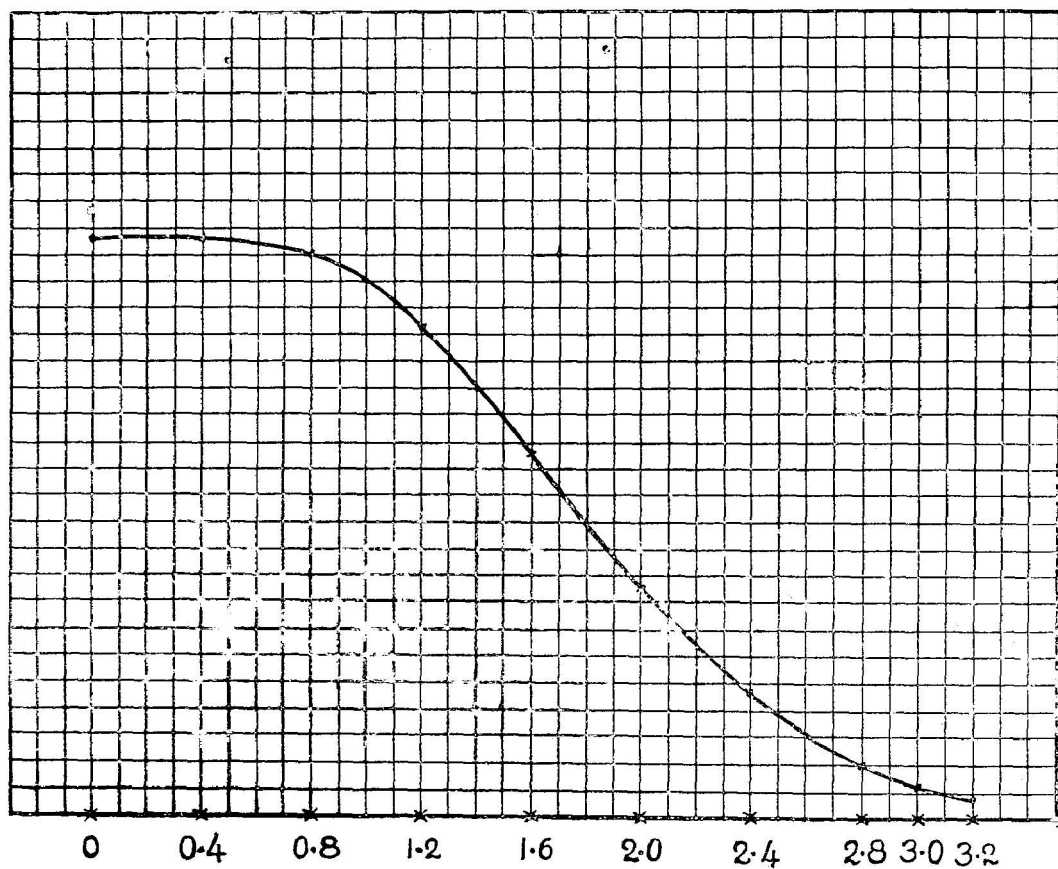
for $s = 0, 1, 2, 3, \dots$

From (3) and (4) we get after a little substitution the final form of $f(x)$ as :

$$\begin{aligned} f(x) &= \frac{2h}{b-a} \mathcal{L}(x) \left[\left\{ \frac{1}{2!} (b^2 - a^2) \right\} + \right. \\ &\quad \frac{1}{4!} \{ (b^4 - a^4) - 6(b^2 - a^2) \} (x^2 - 1) + \\ &\quad \frac{1}{6!} \{ (b^6 - a^6) - 15(b^4 - a^4) + 45(b^2 - a^2) \} (x^4 - 6x^2 + 3) \\ &\quad \left. + \dots \dots \dots + \dots \dots \dots + \dots \dots \dots \right] \end{aligned} \dots \dots \dots (6)$$

By taking the sum of the first two terms as an approximation to $f(x)$ and putting $a = 1, b = 3, h = 2$, we have $f(x) = f_2(x) = \frac{8}{3} (x^2 + 2) \mathcal{L}(x) \dots \dots \dots (7)$

The graph of $y = f_2(x)$ for the range $0 \leq x \leq 3.2$ is drawn below to exhibit the closeness of approximation to the right half of the trapezium. It is also seen that the area under the curve is in defect of the area of the trapezium by 1.1 per cent only.



Road Development in India

BY

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IN the year 1947 immediately after India attained Independence people were all excitement about the shape of things to come in Free India. The Second World War had opened our eyes regarding our deficiencies in many directions. The need for large-scale industrialisation and exploitation of our natural resources was spotlighted as a vital issue. The nation's deficiency in the matter of essential requisites such as food, clothing and housing stared us in the face as problems of the highest priority. Lack of technical personnel to man the various development schemes that had to be launched immediately was another major bottleneck to be remedied.

Seven years have passed since then. It will be appropriate on this occasion to look back and take stock of things that have been accomplished in this interval. Before doing so, let me read out to you this extract from my inaugural address to this Association in 1947.

“ This is a momentous period in the History of India. The long dreamt-of independence for which the great men of this country toiled and suffered is now an accomplished fact. The eyes of other nations and the whole world are upon us. We have a great deal to do. The great responsibility of moulding the destiny of this vast sub-continent devolves on us now. You, budding Engineers, have to share a larger portion of this responsibility than any other set of people, for everybody knows that this is an Engineers' age. The progress of Engineering may in any country be said to be the index of the progress of a nation's civilisation. Till now, we have been a dependent country politically and industrially. Now that the political dependence has been cast off, it is incumbent on us to strive hard to increase the tempo of industrialisation so that the natural resources

The substance of an address to the Annamalai University Engineering Association, delivered on the evening of 30th August 1954.

which we have in plenty are used to the best advantage of the millions of our fellow country men.

“I have often wondered why we in South India are comparatively backward in the matter of industrial pursuits. There is no doubt that this part of the country has produced the best brains and the most versatile talents. The only explanation is to be found in our innate cautiousness and hesitancy to take risks which are incompatible with any large industrial undertakings.

“The Second World War has been responsible for a good deal of industrial awakening in this country. The war created many difficult problems particularly in the field of Engineering and Industrial production. And we can certainly take credit that the Engineers of this country rose to the occasion and were able to render substantial aid by training the required Engineering personnel and technicians and producing Engineering articles that were essential for the prosecution of the war.

“The War has also been an eye-opener to us regarding our unpreparedness and helplessness in many spheres of material activities.

We are hopelessly short of Engineering Experts and Technical Personnel. Many more Engineering Colleges and Poly-technics will have to be started if we are to produce the personnel required to develop the industries that are required to make this country self-supporting.”

Since then several Engineering Colleges have been started in this country, the number of Poly-technics and similar institutions for training technical personnel has been increased. A Five Year Plan is being worked out. And we are in the fourth year of the Plan. In the words of our Prime Minister, the wisest thing done by our Government in the immediate post independence period has been the appointment of a Planning Commission. The First Five Year Plan was actually published in December 1952 though it covers the period from April 1951 to March 1956. The objectives of the plan aimed at initiating a process of development which will raise living standards and open out to the people new opportuni-

ties for a richer and more varied life. This implied (1) the provision of increased employment and production by the most efficient utilisation of the resources of the country and (2) the achievement of the largest measure of social justice possible.

During these seven years of Independence, we may with justifiable pride say that we have many achievements to our credit. Our food problem can be said to have been solved, though some hyper-critics do not attribute all the recovery in this field to the efforts made in the five-year plan but in some measure to the fortuitous coincidence of a seven-year-cycle of favourable seasonal conditions. Several industries have been started and many research stations opened. You must have all heard of the Chittaranjan Locomotive Workshop near Calcutta, The Integral Coach Factory near Madras, The Hindusthan Shipyard near Vizagapatnam, The Sindri Fertiliser Factory, not to speak of the three large refineries being erected, two near Bombay and the third near Vizagapatnam, and several other industries too numerous to be listed here.

Yet the spectre of unemployment is still haunting the country. The several large-scale industries started will increase production. But mere increase in production is not going to solve our problem. The articles produced have to reach the common man who is in bad need of various requisites of decent living. It is only by enhancing the purchasing capacity of the common man that will make it possible for him to acquire the necessities of life and maintain a better standard of living. The National income in India which is estimated at Rs. 255 per capita per annum is far too low for this purpose. It is only by providing employment to the millions of unemployed in this country that the average income of the individual could be raised enabling him to take advantage of the increased production resulting from the large scale industrialisation. Hence the Planning Commission and the Union and State Governments are now more than ever alive to the importance of solving the unemployment problem which has to go side by side with increasing productivity if there should be economic equilibrium in the country.

In the United States of America, Road Transport plays an important part in stimulating economic prosperity. Road Transport is the second

highest industry next only to Agriculture. One job in every seven is held by someone connected with road transportation. Nine million people are thus employed. Compared to this, transport industry in this country is very much lagging behind. Even in the Five Year Plan in which 25% of the total cost has been allotted for Transport and Communications, far greater importance has been attached to Rail Transport than to Road Transport. The provision made for an average annual expenditure of about Rs. 22 crores is altogether inadequate to achieve the targets laid for Road expansion and improvement in the historic Nagpur Plan. It is true that the policy should be to develop an integrated system of transport in the country in which the Railways, the Highways, Inland Waterways and the Airways will each play its appropriate part in its own sphere of useful service to the people. Being a Highways Engineer, you will pardon me if I place greater emphasis on the need for development of the road transport and speak to you in greater detail on this facet of our Planning programme.

The Engineers who assembled at Nagpur on that momentous occasion were asked to think big and make out a bold plan for Post-War Road Development in India. They came out with a plan estimated to cost Rs. 372 crores which at the present level of prices will surely cost well over Rs. 750 crores. As against this, the expenditure envisaged in the Five Year Plan is only Rs. 110.97 crores of which Rs. 33.34 crores is to be spent in the Central sector and Rs. 77.63 crores in the State sector. In addition to this, the Central Road Fund will provide about Rs. 23 crores for expenditure in the State sector and Rs. 27 crores in the Central sector. The latter provision is purely for expenditure on National Highways for the construction of about 1000 miles of missing links and 60 new major bridges besides the improvement of about 4000 miles of existing roads.

Apart from improving the condition of existing roads in the country, there is greater need for the construction of new rural roads connecting the numerous villages scattered all over the country which exist in complete isolation at present, with no access to markets, or existing major roads. It has to be recalled that 80% of the population in this country lives in villages and if adequate facilities are not provided for the villagers to transport the produce from the fields to the nearest market, to send their children to a

nearby school along a well maintained road, to obtain medical and other facilities at short notice, the existence of a good net-work of National and Provincial Highways alone would not serve the purpose.

The road mileage in India when compared to the other advanced countries is hopelessly inadequate. In India there is only one fifth of a mile of road per square mile whereas in United Kingdom it is 2.02 mile per square mile ; in France 1.84 mile per square mile and in United States of America 1.03 mile per square mile. The position of rail mileage is also comparatively less in this country. We have only 29 miles of rail for 1000 square miles whereas in United States of America they have 75 miles of rail per 1000 square miles and 550 miles of rail for 1000 square miles in United Kingdom.

Even though there has been considerable addition to the mileage of rural roads in the past four years the progress cannot be said to be very satisfactory. The large number of Community Projects, National Extension Service Blocks, and other Local Development works organised under the Five Year Plan also make provision for the construction of rural roads to give access to every village coming within the scope of such projects. Whereas the Nagpur Plan envisaged giving road connections to all villages with population of 500 and over, the Community Project provides for giving connection to every village irrespective of the strength of population. The framers of the plan being fully alive to the stupendous nature of the task of providing access to the 5,00,000 villages scattered all over this country and to the futility of attempting to provide finances at Union or State level for the construction of such roads have rightly emphasised the need for public co-operation in this matter and they have linked up the sanction and execution of such works with voluntary contribution to be raised from the public by way of cash payment, gift of lands or free labour to meet a moiety of the cost. The two years of the experiment have already shown the usefulness of these development schemes and the co-operative spirit evinced by the villagers in the execution of such projects. People have slowly begun to appreciate the spirit behind these Nation Building Projects and are casting off their die-hard conservatism. They are showing favourable inclination to part with lands and money for formation of roads to connect their villages with markets and existing roads in the vicinity.

This is indeed a good augury for the future. The intention of the Government and the Planning Commission is not merely to construct such roads at the expense of the Government. This is easily done to the extent the funds permit. What is aimed at is to inculcate a spirit of self-help among the people, the money provided being only to serve as a stimulus to attract public co-operation in the provision of such general amenities to the public. They even go to the extent of saying that the funds provided by Government should only serve as a catalytic agent in the process. The significance of this expression you students of Chemistry are fully aware of.

Just before the commencement of the Five Year Plan the total length of roads in India excluding Municipal roads was approximately 2,35,000 miles and the Five Year Plan provides for an addition of 640 miles of National Highways, 5650 miles of State roads and 16,000 miles of Low Grade roads.

A comparison of the provision made for roads in the Five Year Plan with the accomplishment in the first half of the plan period indicates the following position. As regards National Highways, the plan provided for the construction of 925 miles of new roads of which 640 miles are scheduled to be completed during the period of the plan. In the first two years 240 miles of new construction had been completed and work was in progress on 450 miles of new roads. Regarding improvement to existing roads a total length of 3000 miles were proposed to be taken up during the period of the plan whereas in the first two years, 1050 miles of roads have been improved and work was in progress on a further length of 1500 miles. As against the programme of expenditure of 27 crores in the Central Governments Plan for National Highways for the five years period, 7.11 crores were spent during the first two years of the plan and $5\frac{1}{2}$ crores were expected to be spent in three years. As regards Bridge works 68 large bridges were to be taken up in hand of which 40 were proposed to be completed during the plan period. As against this during the first two years, 17 new bridges were completed and 20 more were under construction in the third year. With regard to State Highways and District and Village Roads the primary responsibility was that of the State Governments and on a rough estimate at least 10,000 miles of new roads would have been completed in the first

three years. The expenditure in the first two years in the States on this account was 28 crores against a total provision of Rs. 73 crores in the plan.

When we speak of figures like 100 crores and 20 crores it is not easily possible for persons like you and me who do not actually possess and handle such large sums to realise the full significance of such a provision or the magnitude of the amounts. It will give you an idea if I say that with one crore of rupees I can lay a Cement Concrete road 12' wide from Madras to Tiruchirapalli, a distance of 200 miles or provide blacktop surface to a road for 1000 miles and so on.

The benefits of the expansion of the road mileages and the improvement of existing roads are not generally fully appreciated. Apart from stimulating Road Transport which in its wake will bring in more taxes, license fees, customs duties etc., to the Union and State Governments, the indirect benefits to the nation are manifold and cannot easily be evaluated. In the expansion of other activities whether it is Education, Agriculture, Public Health or Industries, the road plays a very vital role. The construction of new roads or improvement of an existing one which results in saving time for movement of produce or people from one place to another results in indirect savings to the nation. It is well known that improvement in the surface of a road results in reduction in vehicle running costs by saving on fuel, lubricants, tyres etc., and thus tends to reduce the cost of transport in general. Reduction in cost of transport will reflect in corresponding reduction in the cost of articles produced which again will tend to reduce the cost of living and bring in prosperity all round. It has been established by researches carried out in other advanced countries that expenditure incurred in upgrading the conditions of roads is more than justified by the increased benefits to the nation by way of reduced transportation costs. In this connection it may be of interest for you to know that a committee has been constituted under the auspices of the Indian Roads Congress to go into this question of economics of Highway Transportation with special reference to the improvement of road surfaces. I am a member of this Committee. Statistics are being collected from Transport Organisations all over India regarding the consumption of fuel, lubricants, replacement of tyres, springs, shackles and other parts which have a bearing on the condition of road

surface. It is hoped that when the Committee completes its deliberations and submits the report, there will be a mass of valuable data which I am sure will convince the Government and the public that investment made for improvement of roads will be more than repaid by the reduction in the cost of transport and the indirect benefits accruing to the nation. We, in Madras, should feel happy about having a fairly extensive and well-equipped net-work of road system in our State. We have also the lead in having organised the first Highways Department to look after the construction and maintenance of roads and bridges in the State. This is a result of the realisation of the fact that Road and Bridge construction has now become a specialised job involving the application of latest techniques and use of up-to-date materials.

Considerable advance has been made in other countries in the matter of evolving techniques and materials for road and bridge construction. When I addressed you on the previous occasion I dwelt at length on the extensive researches being carried out in the United States of America and United Kingdom and the very backward position we were with regard to Research in this country. Since then a chain of Research Institutions has been organised in India as you would be well aware of and the Road Research Station at Okla near Delhi is one among them.

Ma dras has not been lagging behind in this matter. We have obtained sanction for starting a Road Research Station in Madras and a sum of Rs. 10 lakhs has been set apart for this purpose already. A large area of land on the Western side of the Engineering College, Guindy, has been proposed to be acquired for this purpose and estimates for putting up suitable buildings and purchasing equipments at a cost of about 10 lakhs have already been prepared and are being sent up for sanction. I have no doubt when the Research Station has commenced functioning and gets into full swing we would play a significant part in the matter of road research in this country. I hope it would result in the discovery of new materials and techniques calculated to reduce the cost of construction and maintenance of roads and bridges and make it possible to provide the large mileage of rural roads required to give connection to every village in this country at a far cheaper cost than is possible at present.
