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The Role of Applied Physics in Industry

by

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It has been the usual procedure in the presidential addresses of the different sections to bring before their fellow workers collected informations regarding new knowledge in a specific domain of the subject, usually in a region in which they have been closely associated. In this way it has been possible to secure a better understanding, a better realisation of some of the aspects of the subject and has been effective in creating an urge in us to carry on the onerous duty of extending the bounds of our knowledge. I would like to present before you all, some particulars of the subjects with which I have been intimately associating myself during the last few years. I have been feeling for some time that time is now ripe to consider the important role which the scientists of our country have to take up in associating themselves with the industrial development of our motherland. It would be necessary for us to take into account and to realise that in the last fifty years applied physics has exerted a more powerful beneficial influence on the intellectual, economic and social life of the world than has ever been exerted in a comparable time by any other agency in history. This may appear to some as a gross exaggeration of its importance but one has to realise the fact that the scope of its interest is nothing less than the understanding and use of all the materials and forces of nature. Its main subdivisions such as applied heat, applied optics, applied accoustics, applied electricity and magnetism and applied mechanics illustrate its scope. Anything we know about these subjects and whatever uses are made of such agencies as light, heat, electricity or the different materials in their different states fall within its field and are the contributions of applied physicists to human welfare.

Average citizen and man of the world have little comprehension regarding applied physics, since though all the different people whose life work really happens to be applied physics do not call themselves by that name. There has been a very interesting trend in applied physics by which great branches of its specialised interests have been appropriated by special groups of applied physicists who call themselves engineers as soon as a systematic method for the application of its principles has been developed in special fields. Thus we have civil engineers, mechanical engineers, electrical engineers, automobile engineers, aeronautical engineers, communication engineers, mining and metallurgical engineers, illumination engineers, motion picture engineers, radio engineers, chemical engineers and diverse others whose operations are wholly or largely concerned with the application of physics to practical ends. Considering "Civil Engineering", which is one of the oldest example of applied physics, one finds that its field is based on the strength of materials, hydraulics and applied optics. Others like the radio engineering and motion picture engineering are based on discoveries within our life time. Turning our attention to metallurgical engineering, a very old practice, and the more recent chemical engineering involving important applications of the chemical science, it is easy to notice that the bulk operations are based on those applications which form the elements of mechanical engineering.

Besides these applied physicists, who group themselves as engineers, one finds astronomers, meterologists, opticians and optometrists and many similar groups, who deal with physical instruments and theories in their special fields of activities. Hence it would not be too much to state that the economic, social and intellectual influence of applied physics is based on the contributions to knowledge, to industry and to the art of living which have all emanated from the diverse elements which are but manifestations evolved from the knowledge of physics. Furthermore, one is cognisant of the fact that new knowledge and applications are rendered available more rapidly than ever before. As examples one can state that modern types of communication, air transport, illumination and electric power have all been developed within our living memory and a number of them like the sound and colour motion pictures, air transportation are still quite young. It would therefore be most illogical to postulate that we have suddenly reached the limit of such developments and one could reasonably expect a comparable and perhaps even greater rate of increase in the knowledge and practical utilisation of materials and forces in the near future.

Let us try to explain our position a little more clearly and let us treat it under three different categories. Firstly, those industries which are based more upon ancient art which has been developed largely by practical experiences as distinguished from systematic research. In this category one finds such activities as the construction of buildings, highways, bridges, and dams ; the production of metals, alloys and textile materials ; the use of natural resources such as power from wind and water, coal and oil. In all these fields there is an art which has been handed down from antiquity and which has been more or less improved by invention and discovery of new materials and methods. In these fields there is noticed a tendency for misunderstanding and conflict of ideas between the so-called practical workers on the one hand and the scientists on the other. The practical men have a great force of tradition behind them and the general public has a feeling of conservatism to oppose the introduction of new materials and new technique supplied by the scientists. The trend towards the scientific attitude is, however, unmistakable and is augmented partly by force of competition and examples, set up by more enterprising members. The second category embraces those industries which have been built upon more recent scientific discoveries. In this, one finds communications, air transportation, motion pictures with sound and colour accompaniments, illumination and the generation and diverse applications of electric power. It is noteworthy that since these industries have been created by research, the organisations, which are taking part in their introduction, would tend to become obsolete as soon as the research activities are allowed to diminish in vigour. The third category includes those groups whose activities rest on the basis of other sciences such as, chemistry, biology, etc. Here one finds the chemical industries, the industry of drugs and medicine which though not directly derived from physics but to which physics is contributing an ever-increasing assistance through tools and measuring instruments, methods and interpretative concepts. One should not lose sight of the fact that it is primarily to the applied physicist that the chemist owes the instruments of precision by which exact knowledge of atomic weight has been arrived at. The investigations of physicists have supplied new knowledge about isotopes, atomic structures and energies, the nature of chemical forces, the arrangements of atoms in solids, liquids and gases. So much so, that now-a-days it is not possible to define the boundary between physics and chemistry since physicists by training are working on problems of chemistry and vice-versa. This joint endeavour of the physicists and chemists, pure and applied, is one of the principal factors in the rapid advance in both the sciences and the industries in general during the last half-a-century. For the field of medicine, the X-ray has been marvelously developed for diagonistic examination and for therapeutic treatment of certain glandular disorders and growths, notably cancer. In the most recent developments primarily for investigations of atomic nuclear structure there is a bye-product exciting new suggestions for medical application. X-rays at a million volt or more have been finding applications for treatment of deep seated cancer. Neutrons produced in nuclear transformations have been found to produce effects different from X-rays or radium and suggest advantageous application in modern therapy. Artificially produced radio active preparations offer interesting possibilities for treatment and open up avenues for a great variety of new physiological investigations on a number of lines such as blood circulation, tissue building and disintegration and the function characteristics of various organs of human and animal bodies. In physical therapy the application of high frequency diathermy and bloodless surgery is but one example of the application of forces studied by applied physicists and applied by the medical practitioner. The application of heat agency in the discriminative destruction of germs and growths is one of the newest forms of physical therapy which operates on the different threshold principle based on resistance and temperature. Quite recently an improved technique is being developed which consists in raising the body temperature locally by means of electromagnetically produced high frequency currents within the body in the region to be treated while the rest of the body is kept within safe limit by special cooling. Finally, it is not an idle boast to state that all the measuring instruments beginning from the thermometers to the portable cardiographs and the multitude of other devices are but the gift of applied physicists to the science and practice of medicine.

I shall now place before you some of the specific industries and would indicate how applied physics is instrumental in their development and growth. In this selection I shall take up first "Building Industry" and 'Metal Industry" as representatives of a class having age old traditions behind it. I shall next take up "Electrical Power Industry" which has been effective in revolutionising all the modern industries, then "Refrigeration Industry" which is the direct outcome of laboratory investigations. From the modern industries I shall choose "Automobile Industry" and "Aeronautics Industry", the last being the youngest of the lot and still probably in the adult stage requiring constant help from researches in applied physics.

Building Industry.

Let us take to our considerations some of the recent applications of physics to old industries such as the "Building Industry". Here one finds that all our structures built to date, rest on earth and a fairly large part of the world's construction cost is in working the earth ; yet through the centuries the very bottoms of our buildings have been designed on an empirical basis. It is only very recently that the investigations regarding soil mechanics have been undertaken. The first International Conference on Soil Mechanics and Foundation Engineering held at Harvard University in the summer of 1937 has disclosed a wealth of outlook and previous lack of understanding of some of the essential aspects of the subject. The problems arising under soil mechanics in connection with design of foundations, the stability of cuttings, while manifestly of the greatest concern to the civil engineers and contractors, have had to be treated empirically in the past owing to the absence of reliable scientific knowledge. For the most part the formulae used for estimating the behaviour of soils have involved such drastic assumption as seriously to impair their validity for anything like general application and it has not been difficult to prove by systematic experiments to demonstrate that such relations as Coulomb's Law, for instance, are to say the least unsatisfactory. The analytical approaches to soil mechanics suggested by Petterson, Terzaghi, Jurgenson and others appear to be far more promising than any of the old methods they supersede. The so called bearing values of the major soil types embodying an accumulation of practical experience, obviously took no account of numerical factors influential in particular set of conditions and were uncertain to a degree and often demanded uneconomical factors of safety and expensive procedures of foundation design. The modern approach to this class of problem seeks rather to understand the mechanism by which settlement occurs, to take account of variations in the types, depth and thickness of the soils in adjoining localities and underlying strata, and to place the effects of weather and secular changes on a rational basis.

At the present time an essential part of research on the subject is to obtain "settlement records", as they enable correlation with the theory to be made and the types of settlement to be classified. From the experimental work so far undertaken it has been found that there are three types of settlement depending on the nature of the substratum. In the case of sand, the movements do not continue for any appreciable time after the construction whereas for clay, the settlement continues for long time after construction approaching a horizontal asymptote. With plastic clays and materials of high organic content a similar gradual settlement is noted but here the asymptote is inclined. The settlement of a building with clay as the most important substratum may be quite small at the end of the construction yet the final or total settlement may be many times greater. The procedure adopted for settlement analysis consists of the following. Firstly, the cores of the various substrata are obtained with a well boring kit and for large structures one has to take the cores up to a depth of 50 ft. The second step is to ascertain the consolidation characteristics of the samples so obtained by laboratory tests. The consolidation characteristics were first studied by Terzaghi with the help of the special instrument devised by him and called oedometer. In this instrument the sample of core material of definite thickness is placed in a brass cylinder between two porous stones which are in contact with water. The conditions of saturation and lateral restraint are thus simulated in the laboratory. Now clay has an open microstructure as has been found from X-ray studies but the dimensions of pores are very small and the resistance to flow is correspondingly high. Under

compression the clay as a whole can suffer volume decrease mainly by the escape of some water from its pores until an equilibrium density is established. Theoretically this would take infinite time but in the laboratory such a stage is attained in about two days. By gradual increase of pressure similar consolidation process takes place and a new equilibrium density is reached. A number of such data gives the relation between the density and effective pressure. This is technically denoted as the void ratio for the material in question. Thirdly, a mathematical analysis of the stresses set up in the substrata by the foundation load is carried out. The theoretical aspect is that of finding an expression for the vertical stress at any point in a semi infinite elastic solid due to a load on its surface. This has been worked out by Boussinesq as early as 1885. In order to arrive at the rate of consolidation one has to take account of the hydrodynamic excess pressure "w" in the pore water causing a flow at a distance "z" from the surface of drainage after a time "t" from that of the application of the load and also the coefficient "c" of consolidation. The fundamental equation has a general nature as $c\dfrac{\partial^2 w}{\partial z^2}=\dfrac{\partial w}{\partial t}$.
If the degree of consolidation "μ" is known from the data of compression at a time "t" and the total compression where μ is the ratio between the two aforesaid quantities, one can solve the differential equation in the form $\mu=f\left(\dfrac{\pi^2 ct}{4d^2}\right)=f(\mathrm{N})$, where "d" is the maximum drainage path. The relation between μ and N has been evaluated for a number of special cases by Terzaghi and Fröhlich with the help of data secured with oedometer. Now for any value of "t", "N" is known from the laboratory tests and "d" from the boring records; the time settlement curve for any part of building structure can be predetermined. It is therefore possible to design a foundation with a measure of certainty not possible with the older empirical methods.

The paramount conclusions of the new work may be concisely stated as follows :—(1) The strains in a foundation which principally determine settlement and soil reaction extend at least to a depth equal to about twice the lesser horizontal dimension of the superstructure. (2) The depth of the foundation below the surface level has an important effect on the distribution of strains in the soil below it. (3) The pile driving formulae are valueless for computing pile capacities in plastic soils owing to the fact that the side friction (which is the main support of the static support in such materials) is temporarily eliminated by water lubrication during driving. (4) The settlement in plastic materials and those containing organic constituents in some proportion is not uniform under uniform loading but tends to be greatest in the middle of the loaded area. (5) Compressibility of the soil materials depends on the initial arrangement, size and shape of the structure and grains as well as on the water content. For fine grained materials compression occurs very slowly and may take many years to complete owing to the water being retained in the pores. Its nature can be understood from micro-structure examinations and suitable laboratory experiments on samples of materials in an undisturbed state. (6) The shearing resistance of granular materials depends on the stresses in the contained water and their ability to escape from the structure. (7) The lateral pressures of granular materials are affected to an enormous degree by small motions of the retaining surface within the mass itself so that arching may entirely modify the pressure and its distribution. (8) The existence of rather deep lying strata of compressible materials may have decisive effects on the surface structures specially, if there be means for the escape of water from them by pumping.

The applications of these ideas have been tested in some of the structures designed and constructed within the last two years and it has been found to be very satisfactory.

It is expected that structural engineers and designers of our land are conversant with this new outlook of their subject and a systematic and coordinated effort should be undertaken by the engineers and the applied physicist to determine the particulars for the type analysis of the underground soils. One could easily note that such analysis is of extreme importance in alluvial tracts where the soil characteristics are of varied nature and the calculations based on older concepts would lead to uneconomic procedures leading to uncertain results. The question of design of subbase structures is getting more and more into prominence due to their need for cold storage, safe deposit vaults and due to the urgent necessity created by the grave international situation for air raid shelters and one cannot overlook the need and urgency of these investigations as they form integral parts of the super-structures.

I shall just touch on another aspect of construction engineers about the more or less universal material used by them viz., the bricks. Brick building is an ancient art and pre-historic in origin, but the recent outlook on the subject would be interesting. Though the strength of the material as derived from different types of clay and fired under different conditions has supplied considerable amount of data yet the surface resistivity of the bricks is only being investigated seriously quite recently. Here the technique of surface reflection, photometry and X-ray analysis has disclosed the porous nature of the surface layers and their effective resisting capacity against weather conditions. The moisture creeping factors of the bricks, by absorption through porous materials as sand plasters, have been the subject of investigation in a few laboratories and have disclosed considerable variation depending on the nature of grain structure and their transformation during the firing stage. This would indeed be a useful subject of investigation for our structural engineers with a closer association with the physicists.

Metal Industry.

I shall now present before you the aspects of another industry which ordinarily appears to have very little to expect from physics. I mean the "Industry of Metals". Historically, it is more than a probability that the first metal industry was entirely one of applied physics. If as many archeologists and historians believe, gold was man's first industrial metal, it was recognised by its colour, and its high specific gravity was used as a basis for its separation from the lighter rock-materials. The "panning" operation is pre-historic in origin. It is, however, used prolifically even to-day, not only in the prospecting for gold but also for many other heavy minerals, for example, tungsten, uranium, copper, lead, thorium and a large number of sulphides. The operation is indeed based on the application of Stokes' law, for the fall of sphere through a viscous medium. In its simplest form, the law states that under the action of gravity a sphere in a viscous medium fairly quickly acquires a constant volocity which is greater in a given medium, larger the sphere and the greater the difference in density between the sphere and the medium. In ore concentration, the pieces of rock are not spheres and the modification due to the shape has to be taken into consideration and has been investigated in some of mining and ore separation institutes. The development of ore concentration machines such as classifiers, jigs, shaking and riffled concentration tables, all take into account the modification of the above-mentioned law in its different modified forms. In the "ore flotation" process, there is the application involving surface tension and adhesive phenomena. It is well known to mining profession that certain minerals, such as sulphides, have greater adhesion for gas bubbles or for oil than for water. Most gangue rock like silica shows more adhesion for water and still more for acidified water. A mixture of sulphide particles and gas bubbles and gangue particles in a solution may result in the bubbles attaching themselves tenaciously to the sulphides until the average specific gravity of the ensemble is less than the solution and one gets the paradox—viz., that heavy minerals float. The preparation of froth, which helps to offer large surfaces for adhesion, has been the aim of these separators and various reagents for froth formation have been introduced from time to time. Quite recently this question of surface adhesion and surface layers has engaged the attention of physicists and the nature of ore surfaces are being investigated with ore microscopes and electron diffraction to elucidate the aspect of surfaces.

If one considers other ore concentration methods, one finds that they could be classified either as pneumatic, magnetic or electrostatic methods and all of them are essentially based on physical principles.

Turning our attention to the smelting operations, one finds that chemistry and physics work simultaneously in many phases. The separation of the slag from the metal is a purely physical process but chemical changes continue to function upto and after ingot pouring. In the furnace itself, there is continual heat exchange. The flow of gases under different temperature and reaction conditions is really regulated by physical laws. In the present practice of separation of flue dust from the blast furnace one finds an important application of physics. The magnitude of the operation would be realised from the fact that for each ton of pig iron, near about five tons of blast furnace gas have to be treated, containing flue dust which is eight to ten per cent of the weight of pig iron and the world production of pig iron for 1938 is more than 100 million tons. The device adopted for the purpose utilises first and second laws of motion as well as Stokes' law. The gas from the top of the blast furnace is allowed to enter a big chamber from the top and the velocity of the incoming gas flow is much reduced. It no longer can carry the same amount of dust suspended in the stream to be mechanically carried along with it. Most of the flue dust is projected to the bottom of the chamber which, after due sintering, is recharged into the blast furnace. Quite recently, when the laws relating to the eddy currents in air and stream-line shapes were being investigated for the design of zeppelin bodies, it attracted the attention of an American blast furnace designer and he utilised the principle by attaching a stationary stream line shape in the path of the incoming high velocity blast furnace gas. The gas hits this stationary surface at a speed of about forty miles an hour and the shape is so designed that the speed is reduced to about four miles per hour and the eddy currents are so far reduced that efficient separation of dust could be secured without any extra expenditure of energy. This new idea of stream-line has been utilised in the metallurgical operation. . Further purification of the gas is effected by proper washing, where high surface energy of water particles in drop form acts as dust catchers. For still further purification electrostatic precipitation process is utilised. This electrostatic precipitation process is well known to physicists, as due to property of ions to act as nucleus for the attachment of fine materials whether in liquid or solid state. It is in principle the same as one finds in Wilson cloud chambers. The industrial use of this principle was first introduced by Sir Oliver Lodge and as a result, one finds the extensive application of the Lodge Cotterel process in the metallurgical industries to separate solid particles from smelter smoke either to make the smoke less objectionable or to recover the valuable flue dusts or both.

In the foundry, most of the operations are based on physical principles. One finds the temperature conditions suitable for casting operations, the nature of the fluid heads, the properties of surface wetting, the viscosity of the molten materials and the frictional flow of the hot liquids. All the above mentioned factors are regulated by laws actually discovered by physicists and have been appropriated and have become integral part of the art of foundry.

The theoretical understanding of the nature of metals necessitates a close examination of their structures as well as the lattice constants. From the industrial point of view, the system iron-carbon is the basis of materials with remarkable properties. It is further well known that pure iron undergoes modification with temperature, in four successive stages α, β, γ, δ, as its temperature is raised from cold to its melting point. In reality these fall under two categories, namely, body-centered and face-centered cubic lattice, and α, δ belong to the first type and γ belongs to the second. The β modification is not due to a change in the structure but indicates a change from the ferro-magnetic to the paramagnetic state. Now considering the alloys, pearlite is a combination of soft ferrite and hard cementite. One finds that the mechanical properties of unhardened steel could be attributed to this. Austenite is the solid solution of carbon atoms in iron and Martensite is the glass-hard constituent of steel formed by quenching. For a long time its character was a matter of difficulty to metallurgists and it has been recently noticed that this form is due to a composite alloy of a definite lattice form. The nature of "prison-bar" steel in which the hard core, formed of chromium steel, happens to be surrounded by a sheath of mild steel, also indicates a peculiar structure formation due to heat-treatment. The mechanical properties of different structures formed by iron and carbon are now being correlated with the theoretical ideas concerning the strength of materials. Theoretically the force required to break a test piece of steel or any other material in tension should be thousands of times larger than what is observed in practice. In trying to explain this anomaly, one has to consider two types of materials, namely, the brittle and the ductile. In the case of brittle material, the failure is due to the fact that it never gives way simultaneously across the whole of its section as one has to assume in theory. In fact, the parting of the crystal starts at one place and proceeds across it since this stress is due to local intensification at the edge of the growing crack. Most probably a sub-microscopic crack in the material is the starting point from which this tearing process begins. In fact Griffith has shown the existence of ultra-microscopic cracks formed on the surface of vitreous silica when one touches it with the fingers ; though the material when freshly prepared possesses very great strength if it is kept uncontaminated from external agencies. A ductile material on the other hand yields to stress. It is distorted as if the atomic planes are able to slide over each other like a pack of cards. This type of plastic flow is well known from the behaviour of a single crystal of a metal in the form of a rod which could be pulled out to several times its length by a very small force. In a general way one finds why metals in a state of purity are ductile whereas complex structures such as intermetallic compounds are in most cases brittle. Atoms of a metal are not held together by bonds and so long as they are in close packing, many configurations may be possible. A distortion equivalent to a glide plane may take place without any serious disturbance of any one of the atoms. On the other hand in a compound having complex pattern a large amount of movement has to take place before any rearrangement of the pattern is possible. The material will not yield as no intermediate stages can occur and it will rather break than yield.

Now considering the subject of other alloys, one finds by taking the metallic elements two by two, the possibility of building up a very large number of alloys. There is a striking difference between the structures produced by alloying two metals than those obtained by the combination of two elements. One could note that to form a chemical compound the products should be present in definite ratios whereas in a binary alloy, each phase constitutes an intermetallic structure extending over a range of composition. When examined by means of X-rays, each of these intermetallic phases is found to have its atoms arranged in a definite manner, some may be of the body centered cubic, others may belong to the face-centered cubic types. In the chromium-aluminium system which has recently been worked out by the X-rays method, phases are so numerous that eleven successive notations are required to designate them.

The extent of the phases can be determined by the consideration of the free-energy of the alloys as obtained by X-ray experiments. The free-energy has to be minimum for the system to be in equilibrium.

$$F = U - T\phi$$

gives a relation between the free energy F, internal energy U, the temperature T, and the entropy ϕ, of the system. The limits of the various phases can be ascertained from a plot of the free-energy values of an intermetallic system against the composition. Even in the case of ternary system, this method has been extended by Bradley and Taylor who determined the phase boundaries of the iron-nickel-aluminium and other similar systems.

The question of phase patterns has been studied by Hume Rothery in considerable detail. His rule enunciates that in similar phase patterns, there is the same ratio of free electrons to atoms. As examples one could cite the case CuZn, a body-centered cubic structure, the ratios of electrons to atoms are 3.2 or 1.5. In brass the ratio is 1.62 ; though this rule has been found on close examination not to hold invariably, one may state that it is true in majority of cases. In order to have a general survey of the whole field of alloys, regarding their structure and properties, X-ray examination of the structure combined with consideration of free energy would lead to a better understanding of the nature of alloy-formation. Then, there is the question of the order and disorder change occuring in some of the alloys in the solid state when they are cooled from high to low temperature. X-ray analysis shows in the case of the alloys of copper and gold having Cu_3Au as formula, the arrangement of the face centered cubic lattice is a random one at high temperature, the position being occupied without any regularity by the gold atoms. On slow cooling through a certain critical temperature however, it is found that the atoms of gold travel to the cube corners and copper atoms to the face centres and an orderly arrangement is set up. The iron-aluminium alloy of the composition, Fe_3 Al, also exhibits this order and disorder change. One might conclude that since the ordering force can be destroyed by temperature, the forces are weak in alloys. Quite the reverse phenomenon has been observed in some alloy systems in which certain atoms pass out of the lattice with the fall of temperature and are disposed of by segregation. The ternary compound of iron-nickel-aluminium, Fe_3NiAl, is found to be homogeneous at high temperature but when slowly cooled it is found to contain isolated clots or groups of iron atoms. This alloy has been extremely useful as the constituent material for powerful permanent magnets.

A very interesting application of the properties of solid solution between two metals, one of which is in a liquid condition and other in a solid state, is technically known as the process of "wetting". The boundary layer, where such solution actually is formed, shows definite characteristics of an alloy formation. This process has been utilised in the manufacture of electric contacts when a tungsten disc is welded to a steel shank. An intermediary thin disc of copper is placed on the top of each steel shank, the tungsten disc being placed on the top of the copper. The ensemble is placed in a furnace with a hydrogen atmosphere until the copper melts. It is found that copper in a hydrogen atmosphere tends to wet both the tungsten and the steel. In fact under the temperature condition, namely, about 1100°C, an adherent of copper and steel is first formed on which the tungsten disc appears to float. With a slight rise in temperature, nearly about 1250°C, the wetting action of tungsten and copper begins. At first the tungsten disc moves about on the surface of the molten copper in an irregular fashion. But as soon as the process of solid solution of the tungsten in copper starts, discs of tungsten align themselves so that they remain centrally on the top of the molten liquid. This formation of the solid solution along with the effect of the capillary forces is also utilised in the manufacture of the welding electrode materials technically known a Elkonite. Powdered tungsten is pressed into briquets and moderately heated but not sufficiently to close the pores. It is then placed in molten copper in a hydrogen atmosphere. Capillary forces cause the copper to fill the pores even above the level of liquid copper, and on cooling one can get the electrode elements sufficiently hard and durable.

Another example of this type of alloy formation is found in the recent manufacture of cemented carbide tools for the machine tool industry. Tungsten carbide first obtained by Moissan is a very hard crystal. The crystal aggregations are porous in nature and brittle due to the existence of sub-microscopic cracks between them. Shrotter and Strauss tried to utilise this property of alloys and found that cobalt in a hydrogen atmosphere has the wetting property for the carbide. They compressed together powders of cobalt and tungsten carbide in a suitable mould and subjected them to moderate pressure. These were then put into an electric furnace with a reducing atmosphere and the temperature raised above the melting point of cobalt. They found that cobalt and tungsten carbide form a suitable matrix which retains the hardness quality of tungsten carbide intact. The material behaves more like diamond than like a metal. This has led also to the utilisation of the carbides of tantalum, titanum and molybdenum. These extremely hard crystals are soluble in each other in a wide variety of proportion at temperatures approaching their melting points. Even at 2000°C, the wetting properties and the solubility are quite high. The solid solution indicates properties different from those of constituent carbides. Tungsten carbide with 6% cobalt bond will easily scratch saphire and inferior only to diamond in hardness. One can have an idea of its hardness from the fact that whereas high speed steel with 18% tungsten contents has the brinnel number 800, that of the carbide with cobalt bond varies from 1400 to 2000. Its compressive strength is 500,000 ℔/sq. cm. It has negligible coefficient of expansion, practically half of invar steel and it is practically non-magnetic. Wide variety of application has been found for these carbides, namely, as substitute for diamond dies, for wire drawing industry and for valves and valve seats of pumps. The only difficulty about the material happens to be that it is incapable of being machined and can be only worked with suitable grinding devices.

Now I would like to present before you just another application of a technique, developed by applied physicist, opening up possibilities for a rapid quantitative determinations of the different ingredients of ferrous and non-ferrous alloys, I mean, spectroscopy. It is well known to my fellow workers that as far back as early eighties of the last century Hartley first made a systematic study for the purpose. His work on beryllium and cerium indicated that when these elements are present in a matrix or body of other materials in small and decreasing quantities, its spectral lines gradually grow weaker and disappear in a definite order. Though Pollock and de Gramont demonstrated the utility of this technique, it remained ignored and forgotten by most physicists and chemists. The first lead in the subject was from the workers of the spectrographic laboratory of the National Bureau of Standards U. S. A. in 1922, when Burns, Meggers, Kiess and Stimson showed that given proper attention, this method leads to fairly accurate results. W. Gerlach in Germany started a systematic investigation to enquire into the different factors necessary to get a correct interpretation of results. The present practice is based on his observations,—namely, the adoption of an internal standard in the material to be investigated. A selected pair of lines, one from the major and the other from the minor constituent of the material in question at a definite ratio of the constituents, is selected. With the gradual diminution of the minor constituent the intensity of the line undergoes diminution in a definite fashion, and it is thus possible to arrive at a fair estimate of the percentage of the minor constituent. Furthermore he found that there are homologous pair of lines in the spectra which have equal intensity under definite percentage ratios of the two elements. Within the last six years more than hundred workers are engaged in the subject and fairly large amount of literature has now been secured. Not only has the technique been efficiently adopted in many of the large metallurgical establishments in America and Europe but also its importance has been instrumental in its adoption by the different ammunition and ordnance factories. In the routine analysis of the different constituent, for example, of the admiralty brasses in England, it has been found that 0.0007% of bismuth could be accurately estimated taking copper lines as the internal standard lines. There has been number of applications of this technique specially in the determination of small quantities where accuracy of results and the speed at which these are obtained has led to their being regularly used in the routine procedure in the metallurgical operations.

Electrical Power Industry.

I shall now consider "Electrical Power Industry," an industry, little more than half a century old and is the direct outcome of physical research. The activity of Michael Faraday may be described as being repeatedly and continuously manifest on a large scale, in most varied manners, giving demonstrations of his law of electromagnetic induction. Magnetic fields in iron link electric current in coils, in generators, motors and solenoids in endless profusion, all over the world. The first electrical engineers were the great physicists,—Kelvin, Weber and others. The common electrical units volt, ampere, ohm, henry, farad, watt with one exception, are named after renowned physicists.

I shall try to limit my subject by considering only the generation and distribution of power and exclude from it utilization or conversion of electrical into other forms as light, heat, or electro-chemical processes. I shall treat however the field of communication which also distributes electrical power but at higher frequencies. In this restricted field I shall deal first with an aspect of physical investigation, which has come to the fore-front recently, viz., the "Electric Discharge in Gases." One meets this phenomenon practically at every point starting from the generation and leading up to the final utilisation circuits, sometimes serving very useful purpose and some other times as a disturbing factor leading to the failure of electrical circuits. The extent of the subject can be realised from the consideration, viz., that the present practice of power generation begins with the production of alternating current from about 11,000 to 30,000 volts. This voltage is then stepped up by transformers to a value suitable for transmission over short or long distances ranging from 22 to 287 kilovolts ; this last value being used for transmission across a distance of 240 miles. For transmission system of intermediate high voltage, one finds it ranging from 2·2 KV to 6·6 KV for local distributions. For domestic and industrial utilisation circuits the voltage would be from 110 to 600 volts.

Let us begin with the alternate current generator with its exciter provided with a commutator and brushes for the generation of direct current to excite its field. Here one finds commutators depending for its proper functioning on the discharge between the brush and the receding commutator segment. Further one finds that the corona discharge in the minute air space between the insulated coil and the slots creating troublesome factors for the generator design. Next is the power switch, which functions by means of an arc between separating electrodes. In the oil circuit breaker, one finds the formation of the arc in a gas bubble formed by the decomposition of the oil. One has to alter the shape and disposition of the bubbles so that a short arc may be capable of performing its task of current interruption.

Let us now consider the transformer. In the design of its components, one has to reckon its different members, viz., the coils, core, the bushings and every where one finds devices whereby the baneful effects of discharge may be safeguarded.

In the transmission lines, as a serious disturbing factor one encounters the high voltage heavy current discharge-lightning. This has led to the provision of the lightning arresters, a device to produce protecting discharge to counteract the damaging effect of the lightning. Its spark-gap has to initiate the discharge and also to co-operate with other elements of the arrester in terminating the discharge after the passage of the lightning. Here the major tool for studying such problems is the Cathode ray tube and the guiding element is the theory of ionisation in gases promulgated by the physicists. The modifications necessary in Townsend's theory to meet the conditions of high pressure and high breakdown voltage have been worked out by physicists but it was Rogowski, who after detailed series of investigations, indicated the need for the modifications. In the recent introduction of the "protective tube" type arrester the spark gap is so ingeniously designed that the discharge passes down a tube made of fibre. The heat of the discharge decomposes some of the fibre into gas which passes through the discharge at such pressure and velocity as to extinguish the power arc at the instant when the current reaches the zero value. The flow of power through the conductor of the transmission lines is due to the magnetic and electric fields surrounding it. One has to avoid the formation of corona discharge from the conductors due to the overstressing of the air surrounding it. The nature of corona discharge has been the subject of study by physicists and engineers and still there remains a considerable amount of empiricism which could only be satisfactorily understood by their joint efforts.

It will be pointed out in the next section how different types of dielectrics are being requisitioned to avoid the harmful effect of these discharges. In the low tension circuits, the power fuses have to be designed to suppress arc formation. In a recent type, boric acid has been introduced to supply steam in small quantities sufficient to check the arc.

Considering the conversion of A.C. power to D.C., one finds the introduction of an arc formation device through the mercury vapour. The mercury arc rectifiers have been rapidly replacing the dynamic type of machinery for conversion purposes in railway, industrial and electro-chemical processes. Here, the cathode spot in the mercury pool is kept in an excited state by the maintenance of a discharge to it from an auxiliary electrode or other main electrodes. In the "ignitron" type of mercury arc tube, which is now finding industrial application, one finds a stationery rod of high resistivity material dipping into the mercury pool. It has been possible to produce at the junction, a concentration of electrical field and current flow, similar to that which occurs at separating contacts, leading to the formation of the cathode spot of an arc. In this tube the stability is maintained by placing the anode directly in the path of the vapour stream coming from the cathode spot. Tanberg observed that the vapour coming from the cathode spot at low pressures has an extraordinarily high momentum and energy corresponding to more than hundred volts. Such high velocity stream formation, though at first doubted by some, has now been confirmed and one can now understand it as due to multiple ionisation of the atoms.

Incidentally one is led to consider the discharge phenomena in low pressure devices such as the thyratrons and grid glow tubes. Here the heated thermionic cathode provides the available electrons when a proper potential difference is applied between the anode and the grid. Here the formation of the plasma suggested by Langmuir satisfactorily accounts for the development of the discharge. In the low pressure gas tubes, there is a curious limit to the magnitude of the current that can pass through it. This sets a limiting value to the current depending on the pressure. When this value is exceeded, a kind of instability sets in, due to which, the discharge is sharply interrupted and re-established repeatedly in an erratic fashion. This has also been accounted for as due to a high degree of ionisation in the gas and it has been suggested that the effect is due to pumping of a high vacuum by the motion of the positive ions.

Let us next discuss in a general way some of these applications in power systems and find the problems common to them. Looking from this aspect one finds the initiation of the useful discharge, then their proper termination and finally the prevention of restarting after the current has attained zero value.

The initiation of discharge in switches and commutators takes place so simply and so spontaneously by the mere operation of separating contacts and the problem of terminating the discharge is frequently so difficult that one does not appreciate the useful function performed by it. If, however, one considers the fundamental aspect of Faraday's Law, one finds that the very existence of the power system depends upon it. Without this device sudden high voltage will develope if the current is actually reduced to zero value quickly at the moment of separation of the contacts. This moment is to be synchronised with the instant of the zero current value of the alternating power so that the electrostatic capacity of the system can absorb energy and thus avoid the dangerous high voltage formation. In general however, the capacity is so small that a very close synchronising would be necessary. Here the discharge in the gas comes as a safe-guard rendering the separation of contacts at the desirable condition, effecting the safe interruption of the circuit at the following zero point of the current cycle.

There have been attempts to interrupt the circuits by dispensing with the separating contacts as in the case of the brush on commutators where the area of contact between the brush and segment, beginning from a maximum, approaches zero continuously as the segment moves away from the brush. Here even as theoretical treatment shows, there is the necessity for a close synchronisation with the course of the current and in practice, it is imperfect. A discharge is operative in the last conduction of current. It is thus manifest that in the case of all successful dark commutation, the final step of the interruption of the current is performed by the glow effect however feeble that may be.

The next problem, viz., that of prevention of the restarting of discharge after the current value has fallen to zero is accomplished by setting up conditions such that either the positive column or the cathode spot or glow cathode cannot reform themselves. For high voltage switches it is the positive column that has to be suppressed. Various means are provided to compel the positive column to have such a small section at the stage when the current has fallen to the zero value that its temperature and degree of ionisation fall to too low values for its re-establishment. Here one has to take into consideration the thermal ionisation theory of positive column worked out by K. T. Compton. The solid barriers with restraining magnetic field in the "de-ion-grid" circuit breakers, the motion of the cold oil under pressure in the "oil blast" breakers and the motion of cold air in "gas blast" breakers, in the "expulsion" type fuses and in "gas blast switches" are the developments introduced in the field of electrical engineering practice.

In mercury arc rectifiers, ignitron, thyratron, grid glow tubes and low pressure gas discharge tubes, the absence of a cathode spot and insufficient voltage to maintain a glow cathode are generally utilised to terminate the discharge upon reversal of polarity.

The low gas pressure raises the voltage necessary to maintain the glow cathode, and so permits relatively high voltages to be handled. However all these devices are subject to a type of failure. Occasionally and at random moments, inspite of the absence of conditions, which the present theory would regard as necessary, a cathode spot is formed at the moment of incorrect polarity and causes a short circuit in the device. The statistical frequency of the occurrences of these "back fires" or "arc backs" is such as to indicate that possibly molecular aggregates are involved which may be impurities on the cathode surfaces or particles in Brownian movement through the gas coming in contact with the anode. It is also found that the frequency of occurrences of these "arc backs" increases rapidly when thirty or forty kilovolts are exceeded, so that the problem of this type of tube for very high voltages remains still unsolved. This phenomenon is of great technical importance, for on its successful solution, rests the high voltage direct current power transmission which is the subject matter of frequent discussions.

It is thus evident how one particular section of physics, viz., "the electrical conduction in gases" crops up at every point in an operating power system. Here one finds how physical theories are applied to solve technical problems and how a close co-operation of the physicists and engineers is essential for further developments.

I shall next treat how the investigations about the nature of dielectrics is of extreme importance in maintaining the power systems. The problem of insulation plays an important role in the development of electrical power industry. Consequently there has been a continuous flow of researches in the field of dielectrics, gaseous, liquid and solid. Broadly speaking these researches are of two general types. The first is that of fundamental character and is carried out by physicists with a view to secure an insight into the mechanism which eventually may lead to an understanding of the useful properties of dielectrics and their behaviour when used as insulators. These properties are dielectric constant, electric conductivity, break-down strength, dielectric loss and power-factor. The term 'dielectric behaviour' usually refers to the variation of these properties with frequency, temperature, voltage and composition. The second type of research is that in which efforts are made by engineers to develope directly improved materials and methods of insulation under the conditions of normal service by utilising any new discovery or suggestion made through researches of the first type.

I shall now present before you some of the recent fundamental researches in the field of dielectrics, particularly those which have a bearing on the application of dielectric properties to the problem of electrical insulation in power industry.

From the standpoint of insulation, the "breakdown strength" of a dielectric is worthy of our first consideration. Persistent efforts particularly those using Cathode ray oscillograph and other methods for following short time phenomenon have however, resulted in a well developed theory which has been universally accepted to explain the mechanism resulting in the electric breakdown of gases. The basis of this theory is the Townsend picture of ionisation by collision for which important modifications, due principally to the part played by the positive ion in the final spark over, have been necessary. Rogowsky and Wallraff have examined the question whether the breakdown over large gaps are due to local high stresses caused by space charges or to ionic bombardment of the cathode. They have concluded that the beginning of breakdown must be attributed to the ionising action of the positive ions. W. F. Bowls has reported that the secondary ionising mechanism necessary for the increased production of electrons requisite to spark over is not due to positive ions in the gas, but to the liberation of new electrons, by the bombardment of the positive ions in the gas on the cathode.

Theories of dielectric strength and breakdown of liquids take a wide range. The Schumann-Nikuradse theory of breakdown ties in the current voltage characteristic in much the same manner as now accepted for gases, and accounts the failure as an internal collision ionisation phenomenon. Kopplemann and Gemant invoke an electrode layer under high stress due to space charge acting on a layer of adsorbed gas, thus creating gas pockets or filaments leading to gaseous ionisation and breakdown. Pure electric breakdown is apparently due to electric collision-ionisation and is recognised only in the purest liquids. Thermal breakdown on the other hand, due to the liberation of gases by heating, in impure liquids, is also evident in many cases.

The breakdown behaviour of commercial insulating oils is of special interest. It has been found that their electric strength increases with their degree of purity.

Large amount of important work has appeared concerning breakdown in solids. In this connection, the conclusion of S. Whitehead, supported by Von Hippel, is worthy of note. According to these authors, electric breakdown in solids is to be understood as an electron collision pheuomenon originating through an execess number of electrons in the lattice. The frictional losses of these electrons are due to the oscillations which they excite by electrostatic influence in passing the ions of the lattice. This friction may be expressed as a function of the electron energy. Beyond the maximum value of this function, the frictional retarded motion of the electrons passes over into an accelerated movement down the potential gradient. Electric breakdown thus occurs primarily through the setting up of electron collision ionisation channels. The directional breakdown noted in crystals is a result of the shape of the excitation function, which is dependent upon the direction of the path with reference to the lattice and also upon the high gradients that result from the accumulations of space charge.

It has been found that that the dielectric strength of soild insulators decreases markedly with increase of frequency.

Researches have been conducted by several physicists to study the process leading from initial ionisation to self-supporting spark or arc discharge. These studies are of special interest because of their obvious bearing on the mechanism of various protective equipments used in power industry.

Incidentally it may be mentioned here that the dielectric losses in oils in the low-frequency range are commonly due to ionic conduction. As the frequency is raised through the radio range, dipolar losses begin to appear. The variation of power-factor or of dielectric constant with frequency is not sharp. This want of sharpness has been attributed to the presence of several constituents having different values of ionic mobilities and dipolar properties.

The problem of "stability" in oils has engaged the attention of physicists for some time. They have divided the oils into two groups. In one group are oils of the transformer type which are used for submersion and in which the important properties are continued fluidity and dielectric strength. In the other group are the oils used as impregnants, as found principally in capacitors and high-voltage cables. In the field of transformer oils, the action of oils on metals has been investigated. It has been found that copper gives the largest quantity of sludge. A relation has been established between the percentage of aromatic constituents in the oil, the frequency of the applied voltage and the amount of sludge formed. It is suggested that to prevent corrosion by insulating oil, copper should be protected by a layer of another metal, tin and lead being found useful for this purpose. It is stated that acid is not a determining factor in corrosion and water has no unfavourable influence on the dielectric loss of transformer oils. Stability in impregnating oils has been a problem for years. Instability is the word used to describe the slow deterioration of high-voltage impregnated paper cables. It has generally been assumed that the causes are to be sought in the impregnating oil. It has been found further that oils having a large ratio of dielectric constant to density show rapid deterioration under oxidation. Gaseous ionisation is known to be an important deteriorating agent probably through changes in the oil due to ionic bombardment. It is not always possible, however, to account for gas pockets or bubbles in well-impregnated insulation.

The impregnated paper power cable continues to receive intense study. The chief problems are the reduction in wall thickness through increased dieletric strength, permanance or stability as inherent in the properties of the basic materials and in the suppression of gaseous ionisation.

G. B. Shanklin has found that there is considerable improvement of power factor of impregnated paper, treated with carbon dioxide during drying and impregnating process. Though lead is not an insulating material, the lead sheath is a vital element in preserving the inherent properties of cable insulation. Improvements of lead sheathing technique are progressing. Especially noteworthy are the vacuum press (Atkinson and McKnight) for limiting oxidation and gas inclusions during leading, the hydrogen press (Shankling) for similar purposes and other measures for greater uniformity of the resulting metal.

Physical structure and dielectric loss of impregnated paper, as related to the amount of contained air and under changes of voltage, temperature, frequency and pressure, are reported by P. Junius. The conclusions are, that the shape of the power-factor voltage curves at different temperatures changes very little in a dielectric containing large amounts of air. On the other hand, the shape of these curves varies noticeably in well-impregnated cable. In the latter case the change of power factor due to temperature change may be much steeper than that for a cable containing air. An increase of pressure by one atmosphere is sufficient to cause a flat loss—curve in a cable which contains much air.

The pressure principle has also received extensive trial. The advantages of pressure on the dielectric are increased dielectric strength and the suppression of internal gas voids. The problem is therefore to ascertain the most reliable method of applying the pressure either by an outside gas or liquid medium or by hydrostatic pressure inside the cable and also the proper ranges of pressures for securing best results. It has been found that oil-filled cable for the higher ranges of voltage is very suitable.

C. A. Grover discusses the feeding of oil to an oil-filled cable, with a detailed development of a method which permits a computation of pressure conditions resulting from temperature variations through the cable and at the feeding points due to load variations. The Callender Company has developed a single conductor impregnated gas-pressure cable with rating of 200 KV., conductor cross-section, 420 sq. mm ; thickness of insulation 23·6 mm. A small space is left between the impregnated paper insulation and the lead sheath. This space is filled after assembly with dry nitrogen at 14 atmospheres excess pressure, the lead sheath being heavily reinforced with copper tapes.

The causes of instability and deterioration continue to occupy our chief attention. In recent years we appear to have passed through a series of modifications in our ideas of the principle causes of cable deterioration. We have noted as chief suspect in successive periods, high inherent power-factor and loss, gaseous ionisation, wax-formation and oxidation. At the moment we appear to be leaving the oxidation period and reverting to that of gaseous ionisation through new methods for studying free gas spaces in the cable.

Careful studies are reported of the stress at which gaseous ionisation begins and as related to different grades of paper. It is stated that both nitrogen and carbon dioxide are the best gases.

Of outstanding interest during the past few years is the progress in the development of new insulating materials of both plastic and ceramic types. Especially noteworthy is the range of physical properties available in several new plastic materials.

Conspicuous among the new plastics are the various ploymerised forms of monomeric styrol. Several investigations have been carried out on the applications of styrene. Of special interest is the control of the induction period of polymerisation and the rate at which the latter takes place. This has permitted the pre-impregnation of paper tape with the monomer with certain admixtures, preventing the sticking of the tape in rolls, polymerisation being effected after application, for example, in a cable joint. The possible use of styrene instead of oil as a saturant for high-voltage paper cable has been suggested.

Improvements have also been made in the composition of artificial rubber which is found to possess a number of advantages over natural rubber. The vulcanised synthetic rubber is replacing natural rubber in high-voltage rubber-insulated conductors, in water-proof insulated wiring and in many other cases. Thermoplastic synthetic rubber materials are replacing fibrous insulating materials in a number of services.

Numerous classes of synthetic resins have also been developed. Since November 1934 about one thousand new trade names for resin offered as insulation have appeared.

Many new ceramic materials have also appeared. New developments in ceramic for insulation are confined principally to those for radio service. All these materials have been introduced as insulators to meet the demand for low dielectric losses in the high-frequency range.

I shall now relate to you just a few items of interest in the field of communication. The rapid expansion of Wire and Radio Communication Systems after the close of the World War in 1918 has necessitated the development of various communication industries utilizing the results of fundamental researches. Limitation of space does not permit me to deal with more than a few of the researches which have been of wide application. In transmission of telegraph signals over circuit, the speed of signalling in bauds or words per minute varies inversely as the product of total capacitance and total resistance of the circuit. The long cable circuit, specially of submarine type, has large capacitance and large resistance and thereby the speed of signalling is reduced to 50 to 60 words per minute. The effect of this inherent capacitance could be overcome by increasing the circuit inductance, that is, by "loading" the circuit.

The case of transmission in message and broadcast programme telephony is more complicated since it involves a large frequency band (i.e., 100-4000 c.p.s. for message and 30-10,000 for broadcast programmes. It follows from theoretical considerations that the product of circuit capacitance and resistance (C.R) must be equal to the product of circuit inductance and leakance (L.G) in order to have the transmission loss and the velocity of propagation same at all frequencies in the band thereby eliminating the frequency and phase distortions. In trunk cable circuits this can be realised in practice by increasing the inductance (L) either by insertion of loading coils wound over magnetic material cores at intervals or by wrapping magnetic material tapes helically over the conductors.

The requirements of a loading coil are (1) the permeability should be high and remain constant for all frequencies. (2) Eddy current and hysteresis losses should be negligible for all frequencies in the band. (3) Leakage or superimposed D.C. should not alter the working point on the magnetisation curve appreciably. (4) The ratio of resistance to inductance of the coil should be very small for all frequencies. (5) Coil size should be as small as possible. For the continuous loading, the magnetic material tape should be very thin about 1/10 of a mm. and at the same time the increase of inductance should be adequate for the purpose, thus requiring a material which has a high permeability for currents of the order circulating in telephone circuits. At the same time the requirements (2), (3) and (4) mentioned above for loading coils must also be satisfied.

Electrolytically deposited iron in the form of dust has served as core of the loading coils till recent years, while 78.5—permalloy tape has replaced iron tape for continuous loading since about two decades. There has been still sufficient room for improvement in both, The audio transformer used in radio equipment or connected between transmission line and programme repeater requires its response characteristic to be strictly uniform from 30 to 10,000 c.p.s. or even more. For cores and pole pieces in loud speakers it is necessary to have high permeability in the range of flux densities between 10,000 and 20,000 gausses. Use of iron dust in audio transformer and of stalloy in loudspeaker fails to give the desired performance.

The study of the magnetic properties of certain alloys of Iron, Nickel and Cobalt has revolutionised the design of loading arrangement in telegraph and telephone transmission systems, of audio transformers and retardation coils in communication equipments and of cores and pole-pieces in loudspeakers.

The properties of these alloys were discovered through exhaustive researches in which all possible combination of three metals—Iron, Nickel and Cobalt—were explored, The factors which contribute to the properties of the alloy are the purity of the elements used in the alloy, their preparation and the heat treatment.

The permalloy series includes nickel-iron alloys containing 30 to 95 per cent nickel. Remarkable variations in magnetic properties with composition are revealed in this series of alloys. The initial and maximum permeabilities of 45-permalloy under standard practice of heat-treatment are 2,700 and 23,000 respectively. For cores requiring flux densities between 10,000 and 15,000 gausses, this alloy in specially useful. The design of cores and pole pieces for loudspeakers may be done with advantage with this alloy. In 78.5-permalloy, quenching gives a higher maximum permeability than in any other permalloy. Initial and maximum permeabilities of 10,000 and 105,000 respectively are developed. The hysteresis loss and the coercive force of quenched 78.5-permalloy are minimum. This alloy is suitable for continuous loading of telegraph and telephone cables. The negligible magnetic losses, non-alteration of magnetic properties with D.C., higher core permeability and material decrease in the size of loading coils have led to use of improved 80 permalloy dust core. For audio transformers, both 3·8-78-5 permalloy and 3·8-80-Mo-permalloy have been used and uniform response between 30 and 16000 c.p.s. have been obtained.

Perminvars are alloys of Nickel, Iron and Cobalt. The constancy of permeability and extremely low hysteresis loss makes 45-25 perminvar the right material for applications where distortion and energy loss are detrimental to high grade transmission. Since the discovery of the properties of perminvars, they have been used for chokes, audio and carrier frequency transformers, filter elements, etc., in equipments designed for high grade transmission. It is specially suitable for continuous loading of long submarine cable circuits for voice-frequency or carrier frequency operation.

Permendurs are alloys of Iron and Cobalt. The principal magnetic property of these alloys is high permeability in the range of flux densities between 10,000 and 25,000 gausses. Permendurs have been applied with success to the design of cores and pole-pieces in loud-speakers and certain special type of telephone receivers where their principal magnetic property has been utilized to the best advantage.

One of the most recent advancements in communication art has been the wide band transmission on circuit between two stations to give as many as 240 or 320 high grade telephone channels simultaneously. The frequency range employed has been .06-1.024 Mc/s or 0.5-2.1 Mc/s depending upon the number of channels. Such multi-channel carrier systems are worked on coaxial cables on four-wire principle. If one and the same coaxial cable is used, two coaxial circuits are provided therein, one of them for transmission of bands in one direction and another for transmission of bands in the reverse direction. If two separate coaxial cables are used for two directions, then each cable consists of one co-axial circuit only.

The co-axial cable circuit is much more suitable medium than open-wire and ordinary cable circuits for transmission of higher frequencies as mentioned above. Among the various advantages like ease in construction and maintenance, lower cross-talk level, etc., may be mentioned the lower transmission loss of pronounced stability. Loss in a transmission circuit is made up of (a) conductor loss, (b) insulator loss and (c) radiation loss. In co-axial cable circuit, the radiation loss is negligible since the unearthed central conductor is entirely surrounded by earthed concentric conductor, and insulator loss is considerably less and further much more stable. The other factors remaining constant, the reduction and stability of loss depend entirely upon the type of insulator used.

When the system was first launched into the field, the coaxial cable had its central copper conductor supported at intervals of $\frac{3}{4}$ inch by hard rubber discs. In recent years, improvement in reduction of insulator loss and obtaining higher stability has been realised by use of polystyrol compounded with rubber or balata under trade name of "Superstyrex". Earliest reference to the electrical characteristics of the solid polystyrol is contained in a patent by Matthews in 1913 where the inventor proposes to replace hard rubber, celluloid, vulcanite, ebonite, glass, wood by polystyrol or polystyrol compounded with rubber. The International Telephone and Telegraph Laboratories Ltd. subsequently took up the studies of polystyrol with particular regard to its application to the insulation of cables. From this study a number of patents evolved dating from 1929 down to the present day dealing first with combinations of polystyrol with rubber, balata, etc. of a thermoplastic nature suitable for extrusion but later with other processes and applications.

The permittivity of polystyrol is low (2.2 to 2.6), and its insulation resistance under A.C. or D.C. voltages is very high even at high temperatures or under high humidity. The material retains its high grade insulating properties even after immersion in water and this fact has led to its use as submarine cable insulator replacing guttapercha. The inclusion of chemical impurities in the material during manufacture appreciably affects the conductance of the material to the extent that power factor varies from .0001 to .0006. While dielectric losses of this order may, from some points of view, be neglected, there are other electrical insulation problems of the type involved here in which the increment of even small dielectric losses are of importance.

Commercial utilization till recent years has been hampered by the absence of supplies of monostyrol, the basic material, on a commercial scale. This is now available from chemical plants in several countries.

In addition to the application in co-axial cable referred to above, wide-spread application of the material to condensers, moulded castings, etc., has already begun. Lacquers have been developed and there is a tendency to use polystyrol for all cases where the highest grade of insulation is in demand.

The outstanding problem is that of employing a hard, glass-like material in situations where toughness, flexibility etc. are required. This necessitates engineering work of a high order, firstly, to design the form of insulation of the cable, apparatus or machine in such a way that a variety of "Superstyrex" may be manufactured to suit ; secondly, to design a suitable variety of "Superstyrex". In the latter problem, little or no reliance can be placed on plasticisers. In general, plasticisers are considered as impurities particularly in applications involving H.F. alternating fields.

I would now turn to the most important branch of communication industries, namely, thermionic vacuum tube industry and consider some of its problems associated with the design and manufacture of modern receiving tubes. During the last fifteen years, the efforts of tube manufactures all over the world have been concentrated to increasing the performance of receiving tubes by evolving several new types for special purposes and by improving existing types by modifications in the mechanical design, improvement in electrodes and cathodes, better arrangement of insulating and spacing the electrodes and exhaustive studies on "gas properties" of electrode materials and on "getter" materials. Some new contrivances like "grid-winding machine" have to be invented. A study of the causes and methods of reducing "noise" has also received due attention. Developments in radio receiver design are continually demanding new types of tube and modifications to existing ones. The manufacturing plant must therefore be sufficiently flexible to allow changes to be made rapidly.

A close control has to be made of the mechanical properties of materials used for components. The manufacturer is limited in his choice of metals for electrodes to only those which have high melting-points and low vapour pressures even at temperatures as high as 1000-1100°C., the temperature reached by the electrodes during pumping operation. Nickel is invariably employed as the plate material and for electrode support wires. It is not sufficiently rigid for the winding wires of grids for which alloys containing molybdenum or nickel-manganese alloys are used. Iron is sometimes used as plate material for screen-grid tubes in which the anode is in the form of two plates.

The manufacture of "grids", which a few years ago, was an extremely laborious process, is now carried out on special machines called "Grid-winding machines" capable of winding as many as 200 to 1000 grids per hour. The grids are wound in lengths of about 60 cm. and subsequently cut into the required lengths. By operation of a cam on the machine, gap or gaps can be introduced in the winding of grids which are necessary for a variable-mu characteristic. It will be realised that uniform mechanical properties of the wire for winding grids (which are of course always slightly larger than the mandrels on which they are finally pressed or stretched) are very essential. Also the strain introduced during final shaping must be small otherwise distortion will occur on heating.

Equally important are the "gas properties'' of the electrode materials. The term "gas properties'' includes not only the amount of gas which may be included in the metal but also the capacity of the metal to re-adsorb gas on its surface. This last factor is in some cases much more important than the first. Investigations of the sources of gas in receiving tubes have revealed that carbon dioxide adsorbed by the electrodes during decomposition of the barium-strontium carbonates on the cathode is much more difficult to remove than the residual gas existing in the metal. The nature of the surface of the electrodes has an enormous effect on this adsorption.

For insulating and spacing the electrodes from one another, mica is generally employed. It is decidedly superior to other possible materials as it is mechanically strong even in very thin sheets, can be formed into flat plates of any desired shape with great accuracy and has just sufficient flexibility to allow the electrode support wires to slide easily through holes without becoming jammed. For temperatures upto 500° C, the best quality ruby clear mica has good insulating properties, is chemically stable and evolves little gas. Above this temperature, mica rapidly decomposes with the liberation of water vapour, one of the most harmful gases in a tube and electrolyses. In tubes where still higher temperatures are reached, alumina, magnesia or steatite, pressed from powdered material to the required shape and sintered at 1500°—1800°C, are employed.

One of the most important features of the modern receiving tube is its highly efficient oxide-coated cathode. The various types of emitters that have at various times been used may be classed as follows :—(a) Clean-metal emitters ; (b) contaminated-metal emitters and (c) oxide emitters. In early days, the desirable features in an emitter were only thermionic emission, mechanical strength and long life. Emission efficiency was not considered a serious problem. All the early tubes were of directly heated filament type. Tungsten suited their requirements very well indeed and may be cited as an instance of clean-metal emitters. Later on, in order to improve the mechanical properties of the tungsten, thorium oxide was added to the tungsten oxide during the manufacture of the tungsten, about 0.7 percent thoria being obtained in the final wire. Langmuir showed that thoriated tungsten had a considerably higher thermionic emission than tungsten at the same temperature. Thorium obtained by reduction of the thorium oxide diffuses into the surface of the tungsten and at temperatures where bulk thorium could not exist, a mono-atomic layer adheres to the tungsten surface with the result that its work function is reduced. Thorium-on-tungsten is an instance of next class. The discovery that the work function of a metal was reduced when a layer of atoms of another electro-positive metal was present on its surface led to much work on caesium-on-oxygen-on-tungsten emitter. The more electro-positive the contaminating metal is, the more the work function is reduced. A still greater reduction in work function is obtained when the contaminating film consists first of a layer of electro-negative atoms such as oxygen and then a layer of electro-positive atoms. The most efficient form of such type of surface yet developed is caesium-on-oxygen-on-tungsten which is another instance of contaminated-metal emitter. The demand for highly efficient cathodes which were inexpensive to operate directed the attention of the manufacturers on the oxide emitters. As the emitter becomes more efficient, the degree of vacuum becomes increasingly important because of the "poisoning" effect of gas on the emitter. Hence a great deal of improvement in the high-vacuum technique had to be achieved. The oxide cathodes are generally produced in the evacuated bulb, and a large quantity of gas has to be removod from the valve before any activation of the cathodes can be attempted.

In indirectly heated types, the cathode is generally a hollow tube of circular, oval or rectangular section which is heated by a filament inside the cathode and insulated from it. The core material is generally tungsten. Since the heater wire normally works at several hundred degrees above that of the cathode surface, it is essential for the wire to have a high melting-point. Another form of core now being used consists of molybdenum-tungsten alloy which has many advantages, since it retains the ductility associated with the molybdenum and yet has a melting-point well above that of molybdenum and a vapour pressure which is negligible below 1750°C. The insulating material consists of a refractory such as alumina which is sprayed on the heater. Magnesia has also been tried as an insulating coating but has been found unsatisfactory for several reasons.

A "getter" is used for maintaining the vacuum in a tube after it has been sealed off. The alkaline earths, the alkali metals and magnesium are common getters. An alloy of barium and magnesium and barium are mostly used at the present moment.

If the metal of which the getter is composed is relatively stable in air, it is welded to a metal disc and dispersed by 'high frequency heating' of the disc. If the metal is an unstable one like barium, it is packed inside a closed container before welding. The high vapour pressure generated on heating is sufficient to burst open the container and the metal is dispersed. For avoiding any deposits over the electrode bonding system, the getter dispersal is usually directed towards the bulb wall by suitable design of container. When very high inter-electrode insulations are desirable for special tubes, alkaline-earth oxide getter is preferred. This is sprayed on to a metal disc in the form of cathode coating and decomposed by high-frequency heating of the oxides. The oxides act as getters when cold. It will be noted that since the emitting cathode itself is a mixture of alkaline-earth oxides, it will also adsorb gas in the active state.

Refrigeration Industry.

I shall next take up "Refrigeration Industry". Refrigeration was born in the laboratory. It remained for a long time confined within the laboratory to be used in various physical investigations. The mechanism and the laws governing it, have been the subject of studies for physicists for more than a century. Even at present the production of low temperatures and the study of the properties of materials under extreme low temperature conditions form the subject of research in special Cryogenic laboratories.

The first industrial application was the production of ice. The first commercial refrigerant was the ammonia gas which on compression liquefies and the quick evaporation of the liquid results in reduction of temperature, so that heat is abstracted from the container sufficient to freeze the water in it. Physical investigations disclosed a number of other substances such as Sulphur Dioxide, Froen, Ethyl Chloride etc., which could be used as refrigerants. One now finds their industrial use all over the world.

It is however well known that the above mentioned mechanism was not capable of being utilised for obtaining sufficiently low temperatures. The search for new principles and new methods were being vigorously pursued and this has led to the means of securing extremely low temperatures. I would like to bring before you, though they are well known, some of the basic ideas underlying these processes whose proper understanding has contributed to the immense growth of the industry. Let us start from the well known properties of gas, namely, that if a gas is allowed to expand freely at high pressures, the molecules would separate and some work has to be done. It is the kinetic energy of the molecules which supplies the energy and accordingly one finds the lowering of temperature. This is evidently converted into potential energy represented by a change in the electromagnetic stress in the molecules. The molecules are not only in constant motion but are in continual collision with one another and these collisions also result in electromagnetic stresses being set up. If it could be imagined that at a particular instant of time all the molecules in a state of collision are stationery, one would certainly get the maximum electromagnetic stress and for that moment whole of the kinetic energy would be reduced to zero. The gas would be at the absolute zero of temperature. At the next instant a repulsion would be set up among the molecules and this would lead to a rise in the kinetic energy. Such exceptional conditions do not arise in practice and one finds an average condition. But this leads to an understanding of the fact that under certain conditions, a gas even on expansion has a tendency to get heated. So there are two effects in every gas—one leading to cooling depending on the degree of separation of molecules and another to heating depending on collisions and this would increase with temperature One thus expects in all gases at a sufficiently high temperature the net effect of expansion to be a rise in temperature. At a certain temperature, namely, the inversion temperature, there is no change and below it a lowering in temperature on expansion. The full realisation of this phenomenon leads to the proper application of the mechanism to secure low temperature.

Let us take the case of air for which the Joule Thomson effect is by no means small. Thus at 0°C air is cooled 0.29 degree centigrade for a fall of pressure of one atmosphere. For a fall in pressure of 200 atmospheres the cooling effect is about 40° C. Roughly speaking if the molecules are about two diameters apart and are then separated so as to be ten diameters apart, they lose about 15 per cent of their kinetic energy. It would appear therefore that to liquefy air which has a boiling point of about 194° C or 79° K, a fall in pressure of 1,000 atmospheres would be required. However in practice expansion to atmosphere pressure is rare, for while the cooling produced depends on the fall in pressure, the work done in compressing a gas is proportional approximately to the logarithm of the ratio of air pressures. Again liquefaction at ordinary temperature is impossible, for the air must be below the so called critical point, which for air is 132° K. This therefore means that some arrangement would be required for a preliminary lowering of temperature. This device, known as "Cold regenerator" or "Heat exchange", was developed soon after the discovery of Joule Thomson effect. In general this consists of two series of closed tubes, through one of which the compressed gas proceeds on its way to the expansion nozzle, and through another, in close thermal contact with the first, the relatively cold expanded gas returns. In fact the realisation of the Joule Thomson effect under proper conditions led Linde and Hampson to design and build machines for liquefaction of air for industrial pruposes.

There is yet another aspect of the same phenomenon. A compressed gas would get cooled when by expansion in an engine, it does external work. The bombardment of the rapidly moving molecules of gas on the piston constitutes the pressure and as the piston moves and does work, some of the kinetic energy of the molecules is transformed into external work. The gas on expansion would have lower temperature. The gas to be liquefied is compressed and cooled by water or air. Part of it then passes into an engine, does work by expansion and is thereby cooled. It then passes into a condenser to act as heat exchange mechanism to cool another part of the gas from the compressor below its critical temperature. To liquefy air, the compressed gas in the engine should be at a very low temperature at about 120° C. This process has been commercially developed by Claude. It is rather interesting to note that Kapitza adopted this method for the liquefaction of helium. The mechanism was capable of reaching below 10° K.

It would not be out of place here to present before you how other properties of material are being utilised for obtaining extremely low temperatures. By the expansion of a compressed gas with or without external work being done, coupled with the cooling due to evaporation of the resulting liquid it has been possible to obtain temperature less than 1° K. While it is most improbable that the absolute zero of temperature can ever be reached, advantage has been taken of the magnetic properties of matter to approach it very closely. In general the magnetic dipoles get arranged in orderly fashion at comparatively high temperatures but there are a few substances, such as iron-aluminium alum, in which random orientations exist at very low temperatures. When these substances are at the lowest temperature attainable by the methods previously described and a magnetic field is created, the field controls the dipole direction and heat is developed. This heat is slowly absorbed by the surrounding substances and when the low temperature is restored, the magnetic field is removed. The dipoles get back to some extent into the disordered condition again and consequently the temperature is lowered. In this way a temperature as low as 0.003 deg. K has been attained.

The need for the refrigeration as a direct agent has largely been utilised for the purpose of cold storage, where rooms are cooled with the help of a bank of coils through which brine is circulated. The brine is usually cooled previous to its circulation by means of suitable refrigerating chamber. Cold storage has been developed within the last few years to such magnitudes that one could find now the refrigerated space in ships bringing food to Great Britain alone amounting to not less than hundred million cubic feet. To-day there are single ships having refrigerated space of over half a million cu.ft. capacity and capable of carrying cargoes amounting to 5,000 tons. The capacity of the public stores in Great Britain alone in 1937 amounts to 50,000,000 cu ft. The annual output of artificial ice is of the order of one and half a million tons and the fishing industry of Great Britain uses more than 700,000 tons of ice annually.

Besides the ordinary ice, one finds now the industry of solid carbon dioxide coming to the forefront. It is rather wonderful that a product, which was used only in the physical laboratories in 1926, has become in bare fourteen years time an important commodity. There are at present in America more than sixty plants for the production of solid carbon dioxide and in other parts of the world, namely, in England, Germany, France, Australia, Japan, South America, Africa, India and Canada, the number of such plants is more than eighty. The properties of solid carbon dioxide are sufficiently unusal to suggest a host of applications. It sublimes directly from the solid to the gaseous state at pressures below 5.11 atmosphere. At one atmosphere the temperature of sublimation is $-78.5°C$. At 5.11

atmosphere pressure the triple points occurs at—56.6°C. The liquid cannot exist at temperatures below that of the triple point nor at pressures below 5.11 atmosphere. Further its critical point is at 31°C at 75.79 atmosphere pressure so that the gas can never be liquefied above 31°C. i.e. above the critical temperature and at high pressure, gas and solid are in equilibrium. It has no true melting point and the latent heat of sublimation at the ordinary atmospheric pressure at a temperature—78.5°C amounts to 136.9 calories per grm. Its high specific gravity coupled with its high latent heat materially reduces the space required for storing a given amount of cooling effect. At present it finds the largest applications in the food industries especially the ice-cream industries of the United States. It has found wide application as preservative for meat and fishes as well as eggs. Only point against it is that it is still ten times dearer than ordinary ice even in large commercial productions.

The cold storage industry has utilised a number of other devices such as humidity recorders, temperature recorders, pressure recorders, ozonisers, all of them products of investigation of applied physicists.

I shall now bring before you the question of air-conditioning and air-hygiene, getting into prominence by the introduction of refrigeration in its various aspects. At first it was limited only to big establishments such as public halls, auditoriums, cinema houses, and air-conditioned trains. But now its size is reduced to that of a household appliance and single room conditioners are at present marketable commodities.

I shall now relate to you some of the indirect applications of this industry. When the demands for the liberal supply of oxygen for medical and industrial purposes first arose, they were met by chemical processes, namely, the oxidation and deoxidation of barium oxide. But soon after the introduction of the air liquefaction processes of Linde and Hampson, oxygen and nitrogen are separated by processes of rectification from liquid air. In 1938 thousand million cu. ft. of oxygen has been consumed in the welding industry. To day single plants are in operation which produce as much as 80 tons of nitrogen per day to be used in the manufacture of cynamide, the nitrogeneous fertiliser formed by passing nitrogen gas over heated calcium carbide. For the manufacture of synthetic ammonia considerable quantity of nitrogen is being daily utilised. In 1894 Rayleigh and Ramsay discovered argon as a constituent of our atmosphere and now the lamp industry alone consumes ten million cu.ft of argon extracted from air every year and at present one thousand million lamps filled with argon are manufactured by the different lamp industries of the world. The annual saving in the light bills of the world exceed many million pounds. Neon is also another constituent of the atmosphere which is extracted from liquid air. Its use in the vapour discharge lamp for advertising purposes and for becon lights is increasing every year. These results could not have been obtained without the refrigerating machineries whose principles and mode of operations have entirely been developed by the physicists, pure and applied.

Automobile Industry.

As an example of application of applied physics to industry I shall next choose "Automobile Industry". This is less than half-a-century old and it could not have been earlier. Let us now consider how different branches of applied physics have contributed to the development of this industry.

Firstly, one finds "Properties of Materials" ranging from the cast iron to the varied types of alloy-steel, aluminium and its alloys, required to form the different members of the engine and its power transmitting mechanism. Steel is required having properties to stand high stresses under high temperature conditions. Here not only high tensile strength but also high torsional rigidity and hardness to resist friction and wear under extreme conditions are necessary. One has also to know how far one could exceed the elastic limits of its running parts to provide against accidents. One should also acquaint himself with the effects of heat treatment of these different classes of materials to impart to them the required properties to serve the needs of the machine. The determination of hardness characteristic is performed by the application of Hertz's theory of impact in the different testing machines evolved for the purpose. In its body building, one must know how far one should exceed the elastic limits under different conditions and to attain the desired plastic deformations. The general knowledge of kinetics is essential for the proper assemblage of its members and their linking, so that one could secure the desired motion and speed under different conditions. One should not disregard the lubricants. The theoretical interpretation of the action of lubricants awaited the work of Osborne Reynolds in 1886, in which he considered the lubricating film to be moving between two parallel plane surfaces. Applying the relations of classical hydrodynamics, he deduced the equation underlying the theory of "thick film lubrication". The specific case of the journal bearing was first satisfactorily treated by Sommerfeld with the assumptions of liquid incompressiblity, absence of turbulence and independence of viscosity on pressure and rate of shear· He considered the minimum film thickness for a given clearance and showed that it increases monotonically with increasing liquid viscosity, journal speed and decreasing load. The journal would rise and shift from an effective solid contact with the bearing until it becomes practically concentric with the bearing as the speed is increased or the load is lessened. The temperature variation of viscosity, however, could not be satisfactorily dealt with as it decreases with increasing temperature and it was Andrade who suggested an exponential formula connecting the relation. The last conference on lubrication held at Hague pointed out the various factors relating to the liquid lubricants mainly from the theoretical standpoint and it was found that in the present state of our knowledge it is difficult to apply any set formulae. The oil in the crank case of an engine under heavy duty will reach 140°C, the bearing surfaces 150° to 200°C and at the upper piston ring grooves and under side of the piston crown temperatures may exceed 250°C. The trend of automobile industry towards lower weight of engine per horse power and higher engine speed increases the difficulty of suitable lubricating oils. So the lubrication specialist is making a continued effort to understand the mechanism of the oil itself under such trying conditions. The susceptibility of the different oils to oxidation and the use of different types of inhibitors to counteract their effect has made some success. The question of film rupture is another factor concerning the contraction of the film, once it has been pierced by projections. To counteract it, one has to requisition another property, namely, that of adhesion of the lubricant to the metallic surfaces. This property is not very well understood and is designated by "oiliness" of the liquid lubricant. The broad field of lubrication demands the attention of applied physicist in the application of the basic work on the theory of liquid state and surface phenomenon.

It is not strange, therefore, that large organisations such as Gulf Research and Development Company, and Standard Vacum Oil Company have started organisations with applied physicists at their helm, to work out this intricate question of proper lubrication.

Secondly, the thermodynamical aspect of the conversion of heat into motive power comes into prominence here. Here one finds, different types of fuels injected into the combustion chamber, suitably ignited, finally ejected out of it into the atmosphere. To any one, who is acquainted with the progress of this industry, it is well-known how the variety of fuels so far utilised required considerable investigations to lead up to the present stage, how ecconomic considerations are showing the need for more easily obtainable fuels.

Recent investigations regarding the design and performances of high speed engines indicate that the lines of enquiry could be fairly grouped under the following heads.

The design of the combustion chamber with its inlet and outlet valves and their proper timing mechanisms ; the determination of the behaviour of the fuels during combustion ; the mechanism of the expulsion of the products of combustion as noiselessly as possible.

Quite an amount of valuable work has been done regarding the proper design of the combustion chamber. The extent of our knowledge however about the actual process of combustion in its different stages, the intermediary products formed and the final consitution of the expelled gases are yet matters of some uncertainty. But this is of extreme importance. The thermodynamic treatment of the petrol engine does not adequately handle that portion of the cycle where combustion occurs. It takes cognisance only of the states of the system immediately before and immediately after combustion. In other words, thermodynamics pay little or no attention at present to the rate of chemical transformation during an engine explosion for want of suitable data, even though this factor determines to a large degree the rate of pressure development as well as the maximum pressure attained. Thus in the thermodynamic treatment of the engine cycle, it is frequently assumed that combustion occurs instantaneously, releasing all the energy of combustion when the piston is at the top dead centre. This is not in conformity with the actual state of affairs.

One has, therefore, to ascertain the nature of the different gases formed in the combustion chamber in the successive stages of ignition and explosion to form an accurate idea of the power developed in the process. In fact, for the study of the new cycle of an internal combustion engine or for the comparison of the different processes, such as, the influence of different heat losses, different combustion lines and different scavenging effects, the entropy diagram is of the greatest help. This has been pointed out in a recent lecture delivered by Prof. Eichelberg before the Institution of Civil Engineers, London. It is well known that the entropy of a gas can be expressed by its temperature and volume as well as by its specific heat. Now specific heat at constant volume, C_v, is du/dt and therefore one must have the energy u theoretically given as the kinetic energy of the molecules. The kinetic theory of gases shows that the rotational movement of the molecules is given by the degree of freedom and is proportional to the absolute temperature. The quantum theory adds the energy of oscillation which is given by Einstein formula when the frequency of the atoms has been measured by spectroscopy or by Raman effect. In deriving the entropy diagram, therefore, a knowledge of the gases developed by combustion is of some importance. Taking purely the chemical view of the problem, one should expect carbon dioxide, nitrogen and water vapour to be the gases formed under ideal conditions ; but in actual practice such ideal conditions are rarely obtained, as every body walking about the streets feels it, when he is encountered with acrid fumes emitted from the exhaust of a passing automobile. Further any chemical method of sample anylysis of the products in the various stages is beset with two main difficulties, namely, the inaccessibility of the flame and its products and the extreme rapidity of the reactions.

It will be my purpose now to show how an applied physicist has come to help the automotive engineer. Quite recently a series of systematic investigations has been conducted in the research laboratory of General Motors Company of America by Rassweiller and Withrow where purely physical methods have been adopted for the purpose. It is clear that the whole phenomenon takes place within the explosion chamber which admits fires and expells the charge thus offering facilities for the observation of the whole process in progressive stages. One has to take successive pictures of the flame production as it progresses and for this reason an experimental cylinder was designed, provided with a suitable glass top which would resist the temperature and pressure prevailing in the chamber. A suitable device has to be provided for a cinematographic film camera which could take rapid successive pictures. For this reason the camera lens has been divided into two parts The fore-part being a stationary one which performs the first stage of the image formation of the flames and the second part consists of a number of similar lenses arranged along the periphery of a disc moving behind the fore-lens. The film in its carrier is so disposed, that whenever any of the moving lenses align with the fore-lens, an image of the flame is formed on it and this movement of the disc can be maintained in synchronism with the motion of the piston of the combustion chamber. In fact this becomes a cinematography of a rapidly moving phenomenon. The speed at which one has to operate this mechanism for an engine of 900 r.p.m. extends from 2000 to 10,000 pictures per second. The flame pictures show that there are two regions of maximum luminosity, one in a region arround the spark plug and another along the forward edge of the flame and they are of distinctly different nature.

To study the nature of these flames, the method of spectroscopy has been requisitioned and here a spectrograph is mounted in the place of the film. In fact the slit occupies the place of the film and the film, as it were, is displaced back to take the instantaneous emission spectrum of the flame. With such an arrangement the spectrographic record shows very interesting details and is compared with the spectrum of the inner cone of a petrol torch operating in air. For the region of the flame front, one finds the familiar CH and C_2 Swan bands. The emission spectrum close to the sparking plug gives no trace of the above-mentioned two band systems. It consists of a very diffuse band system extending from 3800A to 8500A. They have been observed in the flame of CO and O_2 by Weston and Kondratjew and are attributed by them to carbon dioxide. In the ultra-violet region of the spectrum emitted from the flame front and after-glows, one finds OH bands. In addition to the OH bands, a group of very diffuse bands extending from 2800A to 3700A has been observed in flame front but not in the other region. On a careful examination of the literature on band spectra, it is found that Emeleus observed the spectra in the flame of burning ether. Quite recently Vaidya while studying the spectra of the inner cones of ethylene flames observed these two groups and attributed them to the triatomic molecule, HCO. They are entirely absent, however, in the region near about the spark plug. It may be deduced that petrol is not directly burning as a flame in the close proximity of the spark plug.

The sequence of reaction occuring in Bunsen burner flames has been carefully studied long ago (as early as 1892) by Smithels and Ingle and they found only carbon monoxide, hydrogen, carbon dioxide, water and nitrogen above the inner cone of the Bunsen burner flame. No hydro-carbons were present there. One has therefore to consider the mechanism a little more closely. Here one can state that the energy of combustion is liberated first in the flame front due to the reaction of petrol and air. Any small portion of the charge, which at the time of ignition is located near the centre of the combustion chamber, is evidenty compressed by the approach of the flame and forced away from it. When the flame front reaches this portion of the charge, the sudden release of the energy of combustion quickly raises its temperature and this portion of the charge expands. As the flame moves on through the charge, the burnt gas is again compressed and it is forced back towards the spark plug so that the combustion really takes place in two stages. In calculating, therefore, the total energy of the system, one has to take into acoount all these considerations in the calculation of the entropy of the system.

The understanding of this process and the information secured from spectroscopic observations have recently been utilised in the design of some of the modern type of high speed engines and it has been found that their performances are in fairly close agreement with those derived from theoretical calculations.

In the study of fuel injection in the working chamber, one has to consider the action of carburetters, which by proper mixture of air and liquid fuel, produces the spray. Though Rayleigh first investigated the formation of sprays from liquid jets, it was Castleman who applied Rayleigh's theory specifically to the atomisation of liquids in an air stream under conditions similar to those occuring in carburetters. Scheubel determined the drop sizes of the sprays of alcohol—water and alcohol—petrol mixture from a carburetter jet by using spark photography and on the basis of these observations suggested a relation between air pressure, jet diameter, density of the fluid and its viscosity. The disrupted sprays were experimentally investigated by Kuehn de Juhasz, Zahn and Schweitzer and others. From their work it is suggested that the atomisation of liquid jets may be due to the turbulence of the liquid and a critical velocity is required to produce the turbulence.

There has been a large number of theoretical and experimental investigations to understand the proper mechanism of jet formation in different types of fuels and still there are factors awaiting solution.

Now, about the exhaust. One gets some idea of the complicated motions in the exhaust of an engine by a close observation of the swirling motion of smoke issuing from a chimney or the more complicated motion of steam issuing from the funnel of a locomotive or still more complicated motion of the smoke cloud issuing from a big gun after firing of the projectile. The usual formula is based upon the assumption of steady state in the chamber, so that the distribution of energy in the chamber may be ignored and the kinetic energy of the issuing jet equated to the work done in maintaining constant pressure in the chamber. Exhaust of an engine is a transient phenomenon. Hence a great deal of justification is required in applying to it a formula, relating to a steady state, in which it is assumed that the energy in any particular unit of the gas, remains in the same unit throughout its passage through the chamber and the exit pipe and that no unit gains energy from or looses it to neighbouring units. The present state of the theory is in a rather unsatisfactory state. Quite recently a number of experimental studies are being conducted to secure materials for the proper development of the theoretical aspect.

Aeronautical Industry.

Air transportation as such is the youngest of any of the industries so far discussed. In its commercial aspect it is truly an "infant industry''. Not only the designers but also the executives are on the average very considerably younger than the men occupying analogous positions in most other industrial fields. The industry has grown up with an unusual absence of tradition and experience. This is indicative of the fact that all the developments have been based, to a remarkable extent, on the results of research and theoretical calculations. An important feature of aeronautics lies in the extreme narrowness of the margin between success and failure and in the terribly serious consequences which may result in failure. This has placed a tremendous premium on exactitude and has greatly stimulated activity in research of all kinds. All the problems of aeronautics are essentially physical in nature and it is therefore not strange that it has furnished an unusual field for the intensive use of applied physics. I shall merely mention a few of the various branches of physics which have been applied to aeronautical problems and then shall discuss in a little more detail the most fundamental aspect of them.

For any fuel burning power plants, thermodynamics plays an essential part. The difficult problems of heat conduction have to be solved in aeronautics, because aircraft engines demand high pressures for large power output, consistent with low weight and economic fuel consumption. One has to be acquainted with the physics of the airs to reckon the meteorological factors on which are based the different problems of flight. Without this aid, air transport would be almost impossible, since weather troubles would make air services so unreliable as to eliminate most of its economic usefulness. Electricity and magnetism have largely been used in connection with aircraft instruments and radio, two of the elements of vital importance for satisfactory air travel. For noise reduction accoustics have recently been requisitioned. Mechanics in the field of aeronautics is of basic importance. It is well known that many of the basic laws of mechanics were discovered as a result of problems which arose in the attempt to serve specific engineering needs. The classical laws of mechanics formulated in the middle of the eighteenth century had an elegance and generality which attracted mathematicians and theoretical physicists and were far from the actual conditions encountered in practical working. In hydrodynamics, for example, for obtaining exact solutions of the equations, viscosity had been neglected. Frictionless fluids form the basis on which classical hydrodynamics is developed. In engineering hydraulics as developed by practical workers, one finds countless numerical coefficients entirely divorced from the mathematical theory of hydrodynamics and it was extremely difficult to secure generalised relations to form a rational scheme.

It was Felix Klein who first realised this defect in the outlook of engineers and began to build up a school of applied mathematics and applied physics which developed a new interest and new point of view so as to bring engineering and science closer together. Among the group of people associated with him Prandtl, Von Karman and Timoshenko are best known as pioneers in this line. Their main effort had been in obtaining approximate solutions of more specialised equations in which all the essential physical elements of a particular problem are included.

The theory of the aircraft structures is concerned with the transmission of the air forces from the surfaces where they arise and to the useful load which they carry. The aeroplane requires a smooth strong external surface for the air pressures to act on. The external surface has to perform two functions simultaneously, namely, carrying the external pressures and serving as an integral portion of the major structure. In the most modern type of aircraft, the older types of design having a sort of skeleton structure with a covering fabric forming the external surface, have been abandoned. They have been replaced by the so-called "monocoque" type of design in which the surface is made of thin metal and carries a considerable fraction of the major structural loads. The structural members usually have lengths which are very large compared to their transverse dimensions.

The use of the "monocoque" construction and the great slenderness of the structural members result in tendencies towards instability or local buckling. For long compression members like struts, beam flanges etc., the problem has been attacked in two manners. Firstly by designing the structures so that such members have lateral support at frequent intervals. The ratio of length to transverse direction is kept fairly small between supports so that tendency for buckling is reduced. Secondly, carefully worked out cross-sectional shapes are determined so as to distribute a given amount of inertia and increased resistance to buckling. It was easily noticed that in order to prevent buckling of the struts, the thickness would have to be so great and so many stiffening elements would be necessary that the weight would be prohibitive. Wagner, after a careful study, took the bold step of conceiving structures which were allowed and even designed to develop wavy shapes under load. The structure would not buckle in normal flight but goes into a wave state during the brief instant when the loads are higher than normal. The theoretical design formula worked out by Wagner forms the basis of all modern constructions and serves their purpose well.

Turning now to the field of aerodynamics one finds that the earliest scientific analysis of this question was the work of Newton who developed a theoretical formula for the lift of a flat plate. This formula predicted that the lift should be proportional to the square of the angular inclination of the plate to the wind. From this formula, one finds that in order to obtain reasonable lifts, enormous amount of power would be required to drive the plate through air fast enough to retain this high angle of inclination. It was only near the beginning of the present century that actual machines had been built which were capable of flying and on careful examination by the theoretical physicists, it was found that the lift of a plate was proportional to the angle of inclination rather than to the square of the angle.

The relation between the lift and the wind inclination, as well as resistance to forward motion or the drag, depend largely on the wing span i.e., the lateral expansion of the supporting wings. Here was encountered great difficulties in design till 1911 when Prandtl worked out a purely theoretical analysis of the problem, which led to a very simple formula connecting effect of span on drag as well as the relation between the lift and wing inclination. The pressure drag which is the resultant of all normal pressures acting on the surface of a body moving through a fluid has been discussed by Helmholtz, Kirchoff and Rayleigh but owing to the absence of suitable data, these theoretical studies did not find successful application. In 1911 Von Karman showed that by proper 'stream lining' this pressure drag could be completely eliminated. There was yet another factor, namely, the friction encountered by the moving body in motion. This has been the subject of study by Prandtl who showed that the influence of friction was confined to a thin 'boundary layer' close to the surface of a body moving through the atmosphere.

The problem of "stability" i.e., the disturbance effect produced by gust of wind or movements of controls on the normal flying condition, was not very clearly understood. Bryan undertook the study of this problem and arrived at a solution. Though it is highly involved, requiring extensive mathematical technique, yet it forms a basis of calculation and several approximations have now been adopted which have rendered the solution of the stability problem much more easy than before.

The question of "turbulence" attracted some of the best brains in the world for the last fifty years and yet it remains in a state of uncertainty. Osborne Reynolds studied the subject as early as 1883 and arrived at the relation between the different types of fluid motions and their dependence on speed. The distinction between 'laminar motion' and 'turbulent flow' of a fluid and their dependence on the "critical speed" were worked out by him. The so-called Reynolds number and a critical Reynolds number at which transition occurs from the 'laminar' to the 'turbulent' state exist for almost every type of fluid motion. It appears that in practically all cases of technical importance in aerodynamics the range of Reynolds numbers encountered lies far above the critical one, so that a knowledge of the nature of turbulent flow is of extreme practical importance.

Extensive experimental investigations to ascertain the nature of turbulent flow have been conducted. The hot wire anemometer has been widely used for the purpose. Oscillograms of these records have disclosed their complicated nature and still demand careful analysis. The statistical treatment of the problem regarding the mechanism of turbulence by G. I. Taylor may prove to be a very efficient tool which will finally build up a consistant theory.

The recent researches on the aerodynamics of aircraft have attracted considerable attention of eminent applied physicists. Prof. Melville Jones of the Cambridge University has been applying with great success the Pitot-travers method for drag measurements. The measurement of the profile drag on an aeroplane wing by Relf in the compressed air tunnel at the Natioual Physical Laboratory is of great value. In fact the experimental observations now reach up to Reynolds number value of about 24 millions, a value appropriate to the fast modern aircraft.

The co-operation between the actual flight observations and experimental work of the aerodynamic laboratories is now proceeding very closely. The observation of squadron leaders in actual flight are now communicated to the theoretical physicists and to those engaged in wind tunnel experiments so that effective changes in the shape, structure, and surface of the aircraft are being continually modified consistent with the above mentioned back-ground. There yet remains ample scope for research on numerous problems of stability and control. Oscillation problems have been treated generally on the basis that forces at issue are linear functions of velocity and displacements, whereas such factors as controlled and mechanical friction introduce non-linear relationship which has to be taken into account for safe high speed flying.

The whole aspect of aerodynamics leading to the design and construction of aeroplanes is now engaging the attention of an earnest band of workers toiling ceaselessly to obtain practical data by the application of physical principles.

Already the theme has become fairly large and it is not my intention to multiply instances so that one may realise the important role of applied physics in industries. I am afraid, already I have passed the limit of your patience with which you have so kindly favoured me till now. Inspite of this, I can not but draw your attention to the part which applied physics is now playing in agriculture, land survey, meteorology and biological sciences. In the different industries such as, the textile, paper, glass, rubber, abrasives and in various other industries, large and small, the unseen influences of physical methods and appliances are ceaselessly working for better production and economic development. Illumination of our high-ways, schools, workshops, public places of amusement indicate the useful character of the application of physics. I cannot but mention the different aspects of vibrations and forced oscillations in its different effects, modifying our social well-being. In this connection it will not be out of place to mention a very striking example. I would like to refer to you the case of the terrible railways disaster at Bihta in 1937. It is well known that the Government of India appointed a special committee, known as the "Pacific Locomotive Committee", to investigate the cause and suggest remedies for the future non-recurrence of such accidents. I hope all of you are aware that to study the vibrations and oscillations produced in the tracks and engines, a special observation car was fitted up by the Chief Electrical Engineer of G. I. P. Railway, Mr. Mulleneux, and the vibration recording devices designed by the French physicist and railroad engineer Hallade were requisitioned. After the systematic study over several hundred miles of tracks of the behaviour of this special pacific locomotive XB and XA classes of engine, the Committee recommended certain modifications and additions to the engine for its safe running. It was further suggested by the Committee that an enlarged organisation for research and standards should be taken up by the Railway Board to determine the actual vibration and oscillation conditions in tracks and locomotives all over India to ensure their safe running.

The noise and sound measurements are increasingly becoming important in our modern city life. Last but not the least is the contribution of applied physics to industries in the different "Measuring Instruments". Thus in our land survey from the simple measuring chain to the modern aerial photographs for the contour survey of inaccessible region are but examples of its utility. For the control of every industrial process, the measurement of pressure, force, energy, frequency and numerous other mechanisms are finding place. For interchangeable part of machinery and equipment, precision gauges, jigs, ruling engines, projection devices are becoming more and more evident. The measurement of temperature is an important factor in our daily life and the use of temperature measuring devices, the thermometer, the different classes of recording and non-recording pyrometers are becoming absolutely essential in the industry. Regarding electrical instruments, apart from voltmeters, ammeters, energy-meters, frequency-meters and power-factor meters, which are practically developments in one form or other of the galvanometers used in laboratories, one finds a large variety of instruments with modifications suitable for the purpose to which they are to be applied. The steady growth of radio and broadcasting and that of the air-craft created a demand for numerous types of measuring instruments which are primarily born in laboratory but put to industrial use in its multifarious forms. I shall not omit to mention the part played by telescope in scanning the heavens and even now interests of the scientist have not flagged, as is evident from the giant telescope at Mount Palomar being constructed by the California Institute of Technology. Microscopes are being more and more used not only by physicists in their laboratories but also by the biologists, and bacterologists and in the metal industry to study surface characteristics of different materials and in the tool room for precision work. I do not like to exhaust the list. Finally I would say that the contribution of applied physics to other sciences and to industries is becoming increasingly felt and it is expected that in the near future as time progresses, there would be greater and greater demand for applied physics.

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