if s is an integer, or

$$\{\chi^2 - s^2p^2\}\{\chi^2 - (s-1)^2p^2\}\cdots \{\chi^2 - {}^9/_4 p^2\}\{\chi^2 - {}^1/_4 p^2\}\psi = 0 \qquad (8b)$$

if s is half-odd integer. These equations show that a particle of spin s must necessarily appear with $2s$ and $2s+1$ values of the mass respectively, namely, $\pm\chi/s$, $\pm\chi/(s-1)$, ... Thus a particle of spin $^3/_2$ in this theory would necessarily be capable of appearing with two different values of the rest mass, the higher value being three times the lower. These higher values of the rest mass cannot be eliminated by an artifice any more than the states of negative mass (energy) in Dirac's theory of the electron, and we are, therefore, compelled to regard them as different states of the same particle. The above theory has the advantage over the theories of Dirac, Fierz and Pauli[5] that the equation (1) can be deduced naturally from a Lagrange function even in the presence of an electromagnetic field. There are no awkward subsidiary conditions.

1. Dirac, *Proc. Roy. Soc.*, A, **1936**, **155**, 447–59. 2. Fierz, *Helv. Phys. Acta*, **1939**, **12**, 3–37. 3. Madhava Rao, *Proc. Ind. Acad. Sci.*, A, **1942**, **15**, 139–47. 4. Kemmer, *Proc. Roy. Soc.*, A, 1939, **173**, 91–116. 5. Fierz and Pauli, *Ibid.*, **1939**, **173**, 211–32.

SCIENTIFIC RESEARCH AND INDUSTRY IN U.S.A.

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THERE is an old Chinese saying that it is wiser to go abroad and learn than stay at home and teach. Accordingly we find that Chinese scholars for nearly a millennium, between the second century B.C. and eighth century A.D., came in large numbers to the famous universities of India, Taxila and Nalanda, staying there as long as they wished and seeing and learning whatever they wished to see and learn. The hazards of journey in those days were indescribable but where the spirit was daring, the flesh was never too week. The wheels of human progress move continuously and to-day have brought up to top the people of a country which only 300 years ago was a vast pathless jungle. We, from these ancient countries of India and China, cannot too often go to America and see for ourselves how the people there have shaped their lives and institutions which have enabled them to come to the forefront of progress. The Harvard University celebrated the ter-centenary of its foundation only few years ago. The Dean took us round what he called *the yard* of the University, round which the magnificent university buildings have been built. I asked him, "Why do you call it a yard and not a campus?" He said, it was the yard built by the Pilgrim Fathers with high walls all round, where they milked their cows and rested for night so that they might not be disturbed by ravenous wolves or red Indian poachers. The milk from the cows was fed straight to the children on the spot, and thus filled the need of a nursery school in the yard. That was the origin of the Harvard University. The few thousands of aboriginees there did not know that their problem of food and living could be solved in any way except by continuous wars of extermination between the tribes for small fields of maize or fishing grounds. Yet that country maintains to-day 150 millions of human beings with food, in such an excess that, some years ago, maize was burnt and milk thrown into streams to keep up the price level, with a standard of living so high that every family has a motor car of its own and perhaps two radio sets, one for the youngsters and the other for the elders, with one telephone for every eight persons, and with prophylactic and sanitary measures so perfect that the average expectation of life is sixty years. These have been achieved by the genius of the people in harnessing scientific knowledge for the development of the country. In Philadelphia, one cannot help admiring the statue of Benjamin Franklin on a long column which can be seen from miles; the central theme that he preached was that the most certain way of human betterment was improvement in natural knowledge. His countrymen have profited by this advice. They are making continuous efforts to learn the secrets of healthy living, to gain increased mastery over the force of nature, to make new materials having better qualities, to increase the productivity of the soil, and to improve the quality of crops and livestock by scientific breeding and management. All the Research Laboratories have one motto—"The impossible is only what we have not learned to do" and "what is impossible to-day will be commonplace tomorrow."

I believe it will be of more human interest if I were to touch lightly upon the activities of some of the institutions that we visited so that one may draw one's own conclusions regarding American enterprise in research. We visited, among other institutions in Washington —Bureau of Standards where the genial Dr. Lyman Briggs directs the activities of a magnificent group of workers. The average annual expenditure is about 3 million dollars. As a chemist, I was specially interested in the work of Rossini, who has practically revolutionised the technique of separation of hydrocarbons by fractional distillation. His long glass columns, often 60 feet high, give cuts whose boiling-points are constant within one-hundredth of a degree. Physico-chemical properties of these hydrocarbons were being studied with the greatest accuracy—their heats of combustion, free energies, specific heats, etc. This fundamental work is being undertaken because of a conviction in America that synthetic organic chemistry of the future will be based on the hydrocarbons of petroleum and natural gas. The Union Carbide and Carbon Corporation which has now absorbed the American Solvents Corporation, The American Cyanamide Company and the Bakelite Corporation, is now a giant chemical combine which has done pioneering work in this field, *e.g.*, in the chlorination of hydrocarbons, in the preparation of vinyl and acrylic resins, in the manufacture of polyethylene insulating films and sheets, in improvements in the manufacture of power alcohol from ethylene, etc. I was told that polyethylene films, because of their incredibly high dielectric strength, will be *the* insulating material in future electric machine construction and will make possible enormous reduction in the size of electrical machinery without affecting their H.P. The improved polyvinyl acetal resin is exceedingly strong and elastic; can be sandwiched between two sheets of glass without any other adhesive, requires no edge sealing, retains its elasticity at low temperatures with the result that any object striking the glass rebounds rather than penetrates. We were shown films impervious to air, and so strong that air-cushions made by enclosing air within two film surfaces and sealing off the edges by simple heating could easily carry our weights without bursting.

I was interested to find that even the Bureau of Standards under the stress of the war has become a manufacturing concern; the Indian Institute of Science is not the only culprit in this respect. They are the biggest producers of optical glass in U.S.A. in war time. Dr. Bates, the Head of the Glass and Ceramics Division, showed us all the details of manufacture and informed us that annual production now amounted to about 2 million dollars. I wish I were a glass technologist capable of taking a more intelligent interest in the details of the process with a view to their adoption in glass works in India. While talking of glass, I may mention that in addition to shrunk glass made by Corning Glass Works, which has the properties of quartz, there have been two notable developments in glass technology:—one is glass without silica, transparent tubes of which were shown us at the Carnegie Institute of Technology, Pittsburg, and the other, glass fibre with surprising properties, capable of being easily woven. Glass-fibre clothes are being extensively used in filtering strong acids—*e.g.*, it is the only material used in filtering TiO_2 from sulphuric acid mother-liquors. Very thin fibres are now available in many colours and as a non-inflammable and enduring fabric it is pushing its way in competition with linen and cotton for draperies and table covers, and in the electrical industry, as competitor against asbestos.

Another institution which we visited in Washington is the Headquarters Research Station in Bestville Farm of the Bureau of Agriculture. I was told of the work that was being done on nitrogen fertilisers. In all the belligerent countries, ammonium nitrate will be in excess supply after the war. It is a very good fertiliser but its water-absorption capacity stands in the way of its use. Waterproof bags, coating of the nitrate crystals with resins, are some of the lines of attack on which intensive work is being done. But the best work that has been done in U.S.A. is in the production and trial of urea as fertilisers. We in India now are using ammonium sulphate. The sulphate radical is not injurious in calcium-saturated soil, but increases the acidity of laterite soils, where its continued application is fraught with danger. Urea is much less acid-forming than ammonium sulphate and contrary to common belief, is as resistant to leaching as ammonium sulphate. Dr. Parker, the Chief Soil Chemist to the Bureau of Agriculture, is definitely of the opinion that urea is the nitrogen fertiliser of the future, specially in countries like India, which have no deposits of sulphur or gypsum near its coal fields. We were told that urea containing 44 per cent. nitrogen is now being manufactured by Dupont, about 200 tons a day at $5,000 a ton, *i.e.*, at Rs. 165, whereas the anticipated cost of production of ammonium sulphate containing 21 per cent. nitrogen at a factory at Dupont, about 200 tons a day at $50 a Rs. 119 per ton. This excessive cost is due partly to freight charges of gypsum from Rajputana and Punjab fields to the coal fields of Bihar. Our agricultural planners envisage expansion of the ammonium sulphate industry to 2 million tons in 15 years; they will be well advised to plan the production of one million ton of urea instead.

From Washington we went to Pittsburg—the centre of America's Coal and Iron Industry—and were very cordially received by the authorities of the University and the many Research Institutions for which Pittsburg is justly famous. Closely associated with the University is the Carnegie Institute of Technology, which is very well equipped for purpose of teaching and research on metallurgy, ceramics and fuels. There are also in the neighbourhood, the laboratories for researches on coal maintained by the Bureau of Mines which is a department of the Federal Government. The biggest manufacturers of coke-oven-gas, and coke oven plant in U.S.A., Koppers, Ltd., have also their research laboratories there.

Then we have the Mellon Institute whose magnificent laboratories, built in 1937, set up a new standard even in America. This Institute was founded in 1911. The two brothers, Andrew and Richard Mellon, felt that their vast wealth could not be better used than by establishing a Research Institute which will help manufacturers who have little research facilities of their own, to develop new products or improve old processes. Such an Institute will be a strong force in the direction of improving the standard of living through discoveries and inventions. Then, out in the suburbs, are located the famous Westinghouse Research Laboratories which, in reputation, stands only second to the Research Laboratories of the General Electric Company at Schensctady. They have now in Condon one of the ablest physicists of the world to guide their research activities. And about fifteen miles from the city, are the laboratories of the Gulf Research Company where fundamental work is being done in geophysical methods of prospecting for oil, on lubricants and mechanical engineering problems associated with the use of liquid fuels and on the decomposition, polymerisation, isomerisation, cyclisation of paraffin hydrocarbons. The capital cost in building and equipment of each one of these laboratories is of the order of 7 to 10 million dollars, *i.e.*, 2 to 3 crores of rupees, and the annual recurring expenditure is of the order of 2 to 5 million dollars, *i.e.*, 75 to 150 lakhs of rupees. We often asked the question: Does it pay to spend such sums of money on research? We were told that an industry that had been brought into existence with the aid of scientific knowledge could not hope to survive in a competitive world if not continually improved upon by new inventions. A forward looking executive always employs research to meet new competition, to avoid surprises which otherwise might seriously jeopardise his business and to prevent being placed at a great disadvantage should others come to know more about his business than he does himself. We were assured that research paid a handsome dividend, research sections are even more paying than actual operational sections. I am not able to speak with confidence about researches relating to an Electrical Industry, to metallurgy and geophysics in the Pittsburg area, but a few examples may interest you. We were shown a 5 million volt atom smasher of the electrostatic type which will be as powerful a tool for studies of nuclear physics as Cyclotron has been till now. We were shown the new device for producing powerful short-wave radio beams based on the properties of Magneton. We were also shown new and valuable alloys—one having the same coefficient of expansion as hard glass—covar, one possessing great strength at high temperatures which may be useful in high temperature gas turbine, a permanent magnet not more than six inches in diameter which I could not pull out from a steel joist. We admired a very rugged but an exceedingly sensitive instrument for measuring gravity within one part in ten million. Such an instrument can be placed in a lorry and accurate gravity surveys made of any area believed to be rich in mineral resources. I may give a practical illustration. On our way to England we rested for a night in the modern air port of Bahrein Island off the Coast of Arabia in the Persian Gulf. A few years ago it was only a fishing village inhabited by a few poverty-stricken Arab fishermen. I was told that it was included in the prospecting concession of the Anglo-Iranian Oil Company. The older methods of geological prospecting for oil by surface indication did not give much promise of a rich oil field below and the concession was surrendered. But the Americans came later on the scene and their newer geophysical methods predicted rich deposits of oil at great depths. It is well known that large salt deposits under the earth in the form of a dome are generally associated with deposits of mineral oil. Salt has a specific gravity which is less than that of sand and rock which form the earth's crust and its underground existence is often indicated by a diminution in the value of "g". There are other geophysical methods of confirmatory value, *e.g.*, records of seismic waves produced by detonating an explosive at the bottom of a deep hole reflected from various strata underneath, earth currents, etc. Their prediction proved true, and Bahrein Island is now a busy industrial centre producing and refining large quantities of petroleum and the Sheik of Bahrein is no longer a petty medieval landlord but an influential industrial magnate and I hope, a wise modern ruler. The 1,300 miles of air route from Bahrein to Cairo pass through the most inhospitable country of the world—North Saudi Arabia—with no sign of vegetable or animal life anywhere. But we were assured by the Director of the Gulf Research Laboratory that this desert highway will soon be a strategic highway of human civilization. They have discovered an oil-field there, 200 square miles in extent, which contains more oil than the two American Continents—every acre can have a well which will produce 10,000 barrels a day for 80 years. No hole has yet been drilled, but the oil is there as certain as the Sun rises in the East. Plans for building a long concrete channel to bring water from the Mespot rivers to this area are in progress and the survey of a pipe line which will link this field with Mediterranean on one side and Persian Gulf on the other has been completed. This field, now a part of the barren desert, will perhaps witness the rise of some of the richest cities in the world—air-conditioned factories, offices, and homes, with gardens all round. Similar garden-cities will also spring up at strategic points all along this pipe line through the desert. It will be one of the greatest triumphs of human skill and enterprise over adverse nature. Its influence on Indian economy is obvious. Cheap mineral oil will completely transform the methods of power production and furnace construction in the Western Coast of India which will be able to dispense with Bengal coal for such purposes.

One of the main problems of applied chemistry research in the Pittsburg area, relates to the devising of new instruments and apparatus which will place more powerful tools in the hands of industry. I found a team of physicists, physical chemists and mechanics engaged in designing and erecting a mass spectrograph which will give an automatic record of the relative proportion of the particles of different masses that may be present in the discharge chamber. I wondered what on earth would be the industrial advantage of such an instrument. I was told that the analysis in the field of gases that are obtained from different deposits when holes are drilled give valuable indication of the composition of rocks there, and any increase in the proportion of heavy hydrocarbon gases as the drill goes down is an indication of neighbourhood of oil deposits. Again, ordinary methods of hydrocarbon gas analysis which will give, say, the relative proportion of C_{10} and C_9 molecules are extremely difficult, inaccurate and time-consuming; and such an automatic mass spectrograph will do in three hours what thirty chemists might achieve in thirty days. The control of catalytic hydrocarbon reactions by analytical checks will be ensured by this remarkable instrumental development.

The chemical departments of the University and the Mellon Institute were largely absorbed in researches on synthetic rubber, resins, and plastics. They were mostly war secrets but I could gather that the investigators were studying the properties of polymerising and modifying agents with a view both to accelerate and control the process of polymerisation; they were also studying the possibility of manufacturing diamines and polybasic acids from petroleum hydrocarbons. Beneficiation of ores was another subject which was receiving considerable attention. The newer sink and float method for concentration of ore is being applied for treatment of iron ore and coal.

But the two branches of research which overshadow every other activity here were researches on coal and petroleum hydrocarbons. One cannot help noticing the remarkable improvement in design of coke-oven plants by Koppers, Ltd. I saw their most up-to-date plant in New York which handles 1·5 million tons of coal per year, the ovens heated by an auxiliary producer gas system, labour-saving devices on the sealing of doors, careful heat balancing to such a nicety that the basement under the oven can be used for office work, handling of coke oven gas, benzene, toluene, naphthalene, anthracenes, tar, asphalt, by semi-automatic equipment with the result that about seventy men work in the factory starting from transference of coal from the ships to the disposal of final products. Mention may be made of researches on the identification of the primary constituents of coal, on Bergius process of coal tar hydrogenation, on complete gassification of low grade coals by treatment in retorts of special design and special corrosion-resistant material, on production of industrial chemicals like benzene, dicarboxylic and tricarboxylic acids by the oxidation of coal at low temperature and high pressure of oxygen in presence of alkali, on Fischer-Tropsch process using the modern fluid flow catalyst system, etc.

A solid catalyst used in a gaseous reaction often gets inactivated and requires to be regenerated. In industrial practice, we have two reactors containing the stationary solid beds of catalysts connected together by pipes and valves and so worked that, while the desired chemical reaction is being carried out in one reactor, the catalyst bed is being regenerated by suitable treatment in another. This discontinuous alternate process was a question mark to the research staff of the Standard Oil Company and after years of intensive work and by tying together all the work on powdered catalyst they hit upon the idea of keeping the pulverised solid catalyst always suspended in oil vapours, air or steam, as the case may be, and continuously moving it from where it did its catalytic work to where it was cleaned and back to the reactor by regulating at each point the pressure of the suspending gas phase and hence the speed of the catalyst particles. In May 1942, construction of a commercial plant on this basis was started and today 32 fluid catalyst plants are operating with a daily productive capacity of 300,000 barrels of 100 octane gasolene. The American Chemical Engineers predict that within a decade after the war very few chemical reactions will be permitted in industrial practice to take place on a stationary bed of solid material acting either as a reactor or as a catalyst. It will bring about a revolution in many types of chemical plant design.

I regret it will take hours if I were to talk about our visit to other cities and laboratories. American business executive are imbued with the idea that research is the *elixir of life* of an industry, ever keeping it young and vigorous. They think that it is ignoble parasitism to have to depend upon others for up-to-date technical knowledge. They recognise further that the advantage that comes to industry from scientific knowledge comes mostly from the early use of such knowledge and from contact with men who have created such knowledge. How different is the attitude from that of an average industrialist in India who thinks that all that is necessary for the industrialisation of India is to import from abroad plant and machinery and also technical talent for running such plants for, say, ten years and train up our men in the mean time to take the place of foreign experts. They forget that in these days of rapid progress their plant and process may become obsolete in ten years. I wish they may receive better advice and see more light.

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BIOLOGICAL REACTIONS: SPECIFIC, GROUP AND NON-SPECIFIC REACTIONS, AND THEIR SIGNIFICANCE IN EVOLUTION

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WHAT THEY ARE

A FOREIGN protein, ANTIGEN, introduced into a living animal otherwise than through the alimentary canal, PARENTERALLY, produces a substance, ANTIBODY, in the blood. The antibody reacts with the antigen in the test tube, *in vitro*, and in the living body, *in vivo*, in several ways. These reactions are called BIOLOGICAL REACTIONS. As the antibodies are found in the serum, the reactions are also called SEROLOGICAL REACTIONS. Further, as the reactions usually produce resistance or immunity in the body against the foreign proteins (usually the bodies of infecting micro-organisms), they are also called IMMUNOLOGICAL REACTIONS. Briefly, they are antigen-antibody reactions.

The easiest to perform and one of the most sensitive *in vitro* biological reaction is the PRECIPITIN REACTION. A soluble antigen injected into the body produces in the serum PRECIPITIN which produces a precipitate with the antigen. The potency, TITRE, of the precipitin (containing) ANTISERUM is measured by the highest (weakest) dilution of the antigen capable of causing a precipitate. It is usually of the order of thousands. The titre of the antisera used by the writer in detecting the source of blood in a bloodstain is of the order of 1 in 40,000, *i.e.*, it is precipitated by a 1 in 40,000 dilution of the foreign serum. In such a dilution the protein cannot be detected by chemical tests. The biological reactions are, thus, seen to operate over a wider field than chemical reactions.

There are other *in vitro* reactions like COMPLEMENT FIXATION, exemplified by the well-known Wassermann reaction, which detect diseases in the system. This antigen-antibody reaction needs the intervention of