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T. S. Chang and Great Scientists

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(This is a translation into English of an article that first appeared in the 7th edition of the Chinese journal Physics in 2015. It appears here with the permission of the journal.)

T. S. Chang and Great Scientists

Abstract: Mr. T.S.Chang is a famous Chinese physicist, one of the earliest domestic scientists engaged in statistical physics and quantum field theory research, and the first Chinese to start a course at the University of Cambridge in the United Kingdom. Although his life was short, he left an indelible footprint in the history of Chinese scientific development. In his extraordinary academic career, several famous international science masters played an extremely important leading role. This article records these little-known exchanges between Chang and these famous scholars in more detail, as a commemoration of the centenary of Chang's birthday.

Keywords: T.S.Chang R.H.Fowler N.Bohr P.A.M.Dirac A.Bohr Joseph Needham C.Møller

July 12, 2015 (June 1 of the lunar calendar) is the 100th birthday of T.S.Chang（张宗）, one of the pioneers of statistical physics and quantum field theory research in our country.

In statistical physics, T.S.Chang proposed a method to obtain the configuration factor in the system partition function corresponding to Bethe's theory in a system with cooperative phenomena, gave the famous "Chang's Combinatory Formula", and thus proved that the Bethe approximation is completely equivalent to the quasichemical approximation. He is the first person to study the next-nearest neighbor approximation, the first to propose that there may be superlattice phase transitions in adsorption, and the first Chinese statistical physicist whose research results have appeared in internationally renowned journals and in textbooks. In quantum field theory, in research on canonical quantization of constrained systems, he was the first to recognize the quantization problems caused by the appearance of arbitrary space-time functions in classical gauge theory and indefinite multipliers in general systems, and he proposed a preliminary solution. He discovered that there are two different types of constraints and proposed quantization methods that can be used for a large class of models, and made a major contribution to the canonical quantization of constrained systems. He is one of the earliest systematic researchers of the advanced micro-market theory and has a relatively large international influence. He has made significant contributions to the construction of theoretical physics research teams in my country [1][2][3]. He successively served as a professor and researcher at Chongqing Central University, Beijing University, Beijing Normal University, and the Institute of Mathematics, Chinese Academy of Sciences. He was also a professor at the University of Science and Technology of China. In 1957, he was elected as a member of the Chinese Academy of Sciences (now known as an academician).

T.S.Chang was born in 1915 in a family of officials in Hangzhou County (now Hangzhou), Zhejiang Province. His father, Zhang Dongsun（张东荪）, was a philosopher who graduated from the Philosophy Department of Tokyo Imperial University in Japan, and he started to oversee magazines and newspapers when he was studying in Tokyo. He served as the director of the Philosophy Department of Yenching University for a long time.

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In This Issue

Review of Special Issue on the Manhattan Project Nuclear Science and Technology Development at Los Alamos National Laboratory. *Nuclear Technology* 207 (S1), S1-S396 (2021).

Reviewed by Cameron Reed, Department of Physics, Alma College

This review is unusual in that the subject is not a book but rather a special edition of a technical journal. In the summer of 2020, a seminar was held at Los Alamos to commemorate the 75th anniversary of the July 1945 Trinity test. Participants were invited to review scientific and engineering breakthroughs made at Los Alamos during the Manhattan Project and to write up their contributions; the unclassified ones have been published in a special edition of the American Nuclear Society's monthly Nuclear Technology journal. Most of the papers are authored by Los Alamos staff members, but there are also contributors from the Lawrence Livermore and Sandia laboratories, and also the United Kingdom's Aldermaston Atomic Weapons Establishment. The papers are freely available at https://www.ans.org/pubs/journals/nt/volume-207/#number1S

An introductory paper by Los Alamos staff member Mark Chadwick summarizes the 23 contributions. (Chadwick claims to be related to James Chadwick by a common ancestor sometime after the last common ancestor!) These are grouped by topic into seven main areas, although there is naturally some overlap: (i) Nuclear science and engineering (cross-sections, neutronics measurements and calculations, diffusion theory, critical assemblies, and the Water Boiler reactor); (ii) Hydrodynamics (with special emphasis on human and electronic computing efforts dedicated to simulating implosion); (iii) High explosives (in support of the implosion program, plus a paper on the unused Jumbo containment vessel); (iv) Plutonium metallurgy; (v) Nuclear energy and yield (theoretical predictions and experimental techniques to measure the yield of the Trinity test, with the latest assessment coming in at 24.8 +/- 2 kilotons); (vi) Historical technical issues (notably the provenance of the Christy core design, plus a newly-available summary on British contributions to the project prepared by Rudolf Peierls and annotated by James Chadwick); and (vii) Trinity and is impact, including an overview of the test, a discussion of archival material, and recent studies of fallout effects.

With so many different authors and topics, the lengths and styles of the papers vary from technical expositions to more narrative ones, but all will be of interest to scientists and historians alike; no topic of technical work performed at Los Alamos is left untouched. Authors enjoyed access to classified documents held at the Los Alamos National Security Research Center; as a result, much data and many images

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are presented for the first time. Virtually all contributions contain numerous illustrations or photographs of people, places, artifacts, documents, instruments, lists of group members, technical drawings, and original graphs. Each paper is accompanied with a list of references (sometimes over 100), although not all are publicly available.

This volume runs to nearly 400 pages. It is impossible to summarize all of the contributions in a brief review, so I here take the liberty of offering vignettes on those that particularly caught my attention. For the data-oriented, a lengthy paper by Mark Chadwick and collaborators explores the evolution of measurements of key data such as cross-sections, neutron multiplicity, spontaneous fission rates, the energy spectrum of fission-liberated neutrons, properties of moderators and tampers, and estimates of critical mass from both British and American laboratories from the time of the discovery of fission through 1945, with comparisons to today's best values. Small changes in these parameters could have big effects on predicted critical masses and weapon yield, and accurate measurements were the main focus of experimental work at Los Alamos. In some cases, results based on working with incredibly minute amounts of materials were remarkably close to today's best values.

For the experimentally-minded, a Paper by Jesson Hutchison and his collaborators describes the development of criticality experiments where progressively larger spheres of U-235 and Pu-239 were assembled in order to measure neutron multiplicities and extrapolate critical masses. This includes a discussion of four criticality accidents at Los Alamos, including those which took the lives of Harry Daghlian and Louis Slotin. A companion paper by Robert Kimpland and collaborators describes a modern-day theoretical simulation of Otto Frisch's "Dragon" experiments, wherein a slug of enriched uranium hydride was dropped through a hole in a plate of the same material to briefly created a supercritical condition – the world's first fast-neutron chain reactions.

Some of the papers I particularly enjoyed describe the mammoth human and electronic computing effort undertaken at Los Alamos. This is underappreciated in most available histories, particularly the work performed by women "computers" and programmers. Computations for a single implosion simulation could take weeks to run, employing both by-hand work with 10-digit Marchant calculators and plugboard-driven IBM punch-card machines that could do no more than multiply two numbers in one step. An early form of parallel computing was pioneered by simultaneously running differently-colored sets of cards corresponding to different problems through various machines. Many of the postwar pioneers of scientific computing such John von Neumann, John Kemeny, and Nicholas Metropolis were involved in this effort, along with more colorful characters such as Richard Feynman. This work contributed deeply to the implosion program, established computation as being as legitimate an area of research as theory and experiment, and alerted IBM to the potential market for scientific computing: How many of us learned to program in FORTRAN with punch-cards? An amusing story here is that April 1944, Feynman arranged a direct competition between a hand-computing group and IBM machines, with the two in a near-tie for two days until the humans began to fatigue.

Work on "traditional" explosives was also a large part of the work at Los Alamos. Development of armor-penetrating shaped charges had originated in the 1800's, but it was a British explosives chemist, Harold Poole, who in 1942 developed the idea of a workable explosive lens; the British contingent to Los Alamos brought this knowledge across the Atlantic and helped prefect the design for the plutonium implosion assembly. Among the trivia I learned from these contributions is that it was John von Neumann who coined the term "kiloton" as a unit of explosive yield. Another paper in this group concerns the origins of blast-loaded vessels and the history of the "Jumbo" program, which was much more extensive than I had appreciated.

Another under-appreciated aspect of Los Alamos is the chemical and metallurgical research that was carried out, particularly regarding plutonium. This new element proved to be remarkably complicated, possessing several different allotropic phases, that is, different crystalline structures as a function of temperature; six such phases below its melting point are now known. Before this was appreciated, density measurements gave seriously discrepant results, a matter of no small concern for those attempting to calculate critical masses. Two properties of plutonium were particularly troublesome. The more serious, the propensity of reactor-produced plutonium to spontaneously fission due to the presence of a small amount of Pu-240, is well-known as the cause of needing to develop implosion to quickly compress an initially subcritical shell to critical density in order to trigger the nuclear explosion. Less serious but still a matter of concern was that the relatively short alpha-decay half-life of Pu-239 – the fissile isotope used in bombs - renders it some 29,000 times as active as uranium-235. Alpha decays in a bomb core are not dangerous per se, but if as a result of chemical processing the core contains some contamination of light elements such as beryllium or aluminum, a pre-detonation can be triggered by so-called (alpha, n) reactions. In this process, alpha particles strike light-element nuclei and liberate neutrons, which can initiate a chain reaction. This can be controlled by rigorous chemical purification of the plutonium, but this opened up another problem. Plutonium is too brittle to be workable at room temperature; it has to be alloyed to render it malleable. The (alpha, n) problem ruled out traditional alloying elements, and it was not until just three months before the Trinity test that was it found by trail-and-error that gallium could serve as an appropriate alloying agent. (A heavier element is acceptable an alloy because its larger nuclei repel approaching alphas.) I frequently found myself wondering what ancient alchemists and swordsmiths would have made of the near-magic performed at Los Alamos.

A series of papers deals with radiochemical, gamma-ray, and spectroscopic methods of measuring explosive yields. Particularly interesting is a new assessment of the Trinity yield by the technique of detecting "extinct radionuclides," where the abundances of naturally-occurring stable isotopes are very slightly altered by the end-products of decay of fallout isotopes; this is how the new yield estimate of 24.8 +/- 2 kilotons was determined.

The Trinity test has an associated set of often-told stories, one of which is how Enrico Fermi estimated the yield by dropping scraps of paper and observing how far they were blown by the shock wave. However, Fermi never detailed how he arrived at this number, and this is taken up in a paper by Jonathan Katz. I was expecting perhaps a simple pressure/displacement argument, but the requisite atmospheric hydrodynamics is much more complicated, another example of Fermi's command of

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April 2022 FHPP Session Report

"The History of Astrophysical Observation"

By Paul Halpern, Department of Physics, St. Joseph's University

Matthew Stanley

First talk

"Merging the Sun and the Stars: the hybrid images of the 1919 eclipse" was given by Dr. Matthew Stanley, who teaches the history and philosophy of science at New York's Gallatin School of Individualized Study.

His excellent talk began with a discussion of the early history of capturing astronomical images, first through drawings, and then, in the late 19th century, through photographs. He demonstrated how, as such photography improved, astronomers such as Frank Dyson were in the forefront of understanding the impact of the new technology.

That training came into great use when Dyson teamed with Arthur Eddington to test Einstein's general theory of relativity and its prediction of light-bending during the solar eclipse of 1919. That testing led to the widespread acceptance of general relativity and fame for Einstein.

Second talk

"History of Black Hole Visualizations," was delivered virtually by Emilie Skulberg, postdoctoral researcher at the University of Amsterdam.

Her outstanding lecture explored the various ways black holes have been depicted, from Penrose diagrams, to modern images of the "shadows" surrounding black holes. She emphasized that one of the key points, suitable to any artwork, was capturing the viewpoint of the observer, and giving him or her a sense of what approaching such an object might entail. Some of the choices made for realistic depictions might be counterintuitive in nature.

Third talk

"Visualizing and Historicizing Cosmic Radiation," was delivered virtually by Connemara Doran, Visiting Research Associate at the Harvard University Department of the History of Science.

She gave an excellent lecture about how the instruments on various satellites detecting the cosmic background radiation, from COBE to WMAP to Planck, offered increasingly powerful imagery of the CMB, enabling increasingly precise estimates of cosmological parameters.

Review of Special Issue on the Manhattan Project

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both theory and elegant experiment.

The last paper in this volume describes an extensive study carried out by the National Cancer Institute of Trinity exposure and likely excess cancers broken out by ethnicity and cancer types across all New Mexico counties. Predicted casualties were small, but eye-catching color-coded maps of one-year radioactivity exposures and the distribution of residual plutonium serve as sobering reminders of the impacts of even "low-yield" nuclear explosions. Both effects were concentrated to the northeast of the explosion site by prevailing winds.

While I was familiar with many of the aspects of Los Alamos covered in these papers, I often found myself thinking "I knew that research on X was an important part of the wartime effort at Los Alamos, but I hadn't realized just how important." Aspects of physics, chemistry, metallurgy, computing, electronics, ordnance, and ballistics all had to be coordinated and come together for a successful outcome, and there was no lack of surprises along the way. These papers also reinforced for me the gulf between the Allied and German nuclear programs: The latter had nothing remotely close to Los Alamos, let alone Oak Ridge or Hanford.

This volume should be in the collection of anybody interested in the Manhattan Project and Los Alamos; it is a superb complement to Hoddeson et al.'s Critical Assembly (Cambridge, 1993) and Robert Serber's Los Alamos Primer. Manhattan and Los Alamos still stand as staggering achievements, and there is still much to be learned about them.

Cameron Reed is the Charles A. Dana Professor of Physics (Emeritus) at Alma College, Michigan. He served as Secretary-Treasurer of the (then) APS Forum on History of Physics from 2013-2019. His book "Manhattan Project: The Story of the Century" was published by Springer in 2020. Now formally retired, he continues to teach, pursue research on the Manhattan Project, and serve as an Associate Editor with American Journal of Physics.

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During the Anti-Japanese War he spent half a year in the Japanese prison, and he was one of the leading members of the China Democratic Alliance during the Anti-Japanese War. In 1948, in order to protect the cultural city of Beijing and the well-being of the people of the city, he took the initiative to go back and forth between the Fu Zuoyi（傅作义），commander of the Chinese Nationalist Party and the People's Liberation Army, trying his best to negotiate peace, and he became a hero of the peaceful liberation of Beijing. In the early days of liberation, Zhang Dongsun served as a member of the Central People's Government and had a leading position in the China Democratic League, but in 1952 he was criticized in the thought reform movement. Finally, because of the "American espionage case", he was dismissed from all positions, expelled from the China Democratic League, and became a civilian who "handled the contradictions among the people and retained his position as a professor at Peking University". In 1958, he was transferred to the Beijing Literature and History Museum. He was arrested in 1968 during the Cultural Revolution and died in prison in 1973. The ups and downs of Zhang Dongsun's life had a considerable influence on T. S. Chang. He was smart and eager to learn since he was a child. Families provide their children with good educational conditions, but most importantly, they let them develop their own interests and choose their own educational path. These combined factors made him able to enroll in the Physics Department of Yenching University at the age of 15, transfer to Tsinghua University the following year, graduate with a Bachelor of Science degree at the age of 19, go to Cambridge University as a graduate student at the age of 21, and obtain a doctorate at the age of 23. At the age of 25, he was hired as a professor at Central University and officially became the youngest professor at this age.

A very important factor in T. S. Chang's ability to become an outstanding scientist is that he received the guidance and help of several of the most famous international science masters. T. S. Chang went abroad twice. From 1936 to 1939 he studied for a doctorate at the University of Cambridge in UK and undertook research in scientific research institutions in Denmark, Switzerland and France. From 1945 to 1948, he went to Cambridge, UK, as a visiting scholar, and then to the United States and Denmark. The scientific masters he met, including Fowler, the Niels Bohr family (including Aage Bohr), Dirac, Needham, etc., in different periods and in different aspects and in different forms, greatly contributed to his academic career. In this article, we describe this career in more detail as a memorial to T. S. Chang.

Fowler and T. S. Chang

In 1936, Chang was admitted to the fourth class of Boxer indemnity mathematics students studying in the UK, and in September, he arrived at Fitzwilliam House College, Cambridge University, UK, where he studied statistical physics under the tutelage of Fowler in the Department of Mathematics [4].

In Britain in the 1920s through the 1940s, Ralph Howard Fowler (1889-1944) was a very important figure in promoting the development of mathematical physics and quantum theory in Cambridge. Elected as a fellow of Trinity College in 1914, Fowler served and was wounded in the Royal Marines artillery during World War I. The experience of being exposed to applied mathematics during the war made him interested in physical problems. After returning to Cambridge in 1919, he became friends with Ernest Rutherford (1871-1937), the new director of the Cavendish Laboratory, and married the latter's only daughter in 1921. In 1922, Fowler published a series of papers on statistical mechanics, developing methods for calculating the distribution of energy in quantum systems.

Fowler founded the earliest modern theoretical physics school in England, the Fowler School. Due to administrative regulations, the theoretical physicists in Cambridge were all in the Department of Mathematics at that time and had little contact with the Cavendish Laboratory. But because of Fowler's special relationship with Rutherford, he became a unique and important link in Cambridge between theoretical workers and Cavendish experimental workers. He is both a link between theoretical and experimental physics at Cambridge and an active communicator of quantum theory [5][6][7][8][9]. It was he who introduced his student Dirac (Paul Adrien Maurice Dirac, 1902-1984) to de Broglie's paper on matter waves in 1923. He encouraged and guided Dirac into the field of quantum mechanics. He also introduced Dirac to Heisenberg through Bohr (Niels Bohr, 1885-1962), leading to Dirac's discovery of quantum mechanics in 1925. In 1925 Fowler was elected a member of the Royal Society, and the following year he took the lead in applying the new quantum statistics created by Fermi and Dirac to the study of white dwarfs, thus becoming one of the founders of modern theoretical astrophysics. (His student S. Chandrasekhar introduced the Chandrasekhar limit of white dwarfs on the basis of this theory in 1930, and won the Nobel Prize in 1983.) In 1932 he was elected to the newly created Plummer Chair of Thermodynamic Physics. In 1938, he succeeded Lawrence Bragg as director of the National Physical Laboratory. He died in 1944. Fowler's Statistical Mechanics, published in 1929, and Statistical Thermodynamics, published in 1939, have long been used as major reference books by the statistical physics community.

Fowler was an outstanding and productive mentor. In 1922 he became the only postgraduate supervisor in the newly established PhD degree program in Mathematical Physics at the University of Cambridge, and during his tenure as supervisor from 1922 to 1939 he had 64 postgraduates according to registration records. These include at least 15 members of the Royal Society and 3 Nobel Prize winners: P.A.M Dirac, N.F. Mott, and S. Chandrasekhar [10].

When Chang arrived in Cambridge, Fowler had just returned from lecturing at Princeton University. According to the literature [9], Fowler was very busy, instructing many students, and he rarely had time to meet individually with them. However, from the research papers Chang completed at Cambridge, it is clear that he adapted to Fowler's guidance and quickly entered the forefront of statistical physics research.

In the mid-1930s, the research focus of statistical physics was shifting from quasi-free particle systems such as ideal gases and low-temperature solids to cooperative systems with relatively strong interactions. Cooperative phenomena and phase transitions of alloys and solutions became the focus of research. The processing method proposed by H. Bethe in 1935 is a very important development. Previously, in 1934, W. L. Bragg and E. J. Williams had

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made a very simplified assumption. They had assumed that the average energy of an atom at a given lattice point in a metal is determined by an assumed average ordering of atoms throughout the solid. Bethe argued that this energy would depend on the configuration of the closest neighboring atoms. The influence of more distant atoms was still used as the effective field for these nearest neighbor atoms This produced a refinement of the Bragg and Williams calculation that better described the transition through a superlattice phase transition to an ordered solid as the temperature is lowered. Specific heat and other quantities could then be more accurately calculated These studies actually created a very important new field of statistical mechanics research.

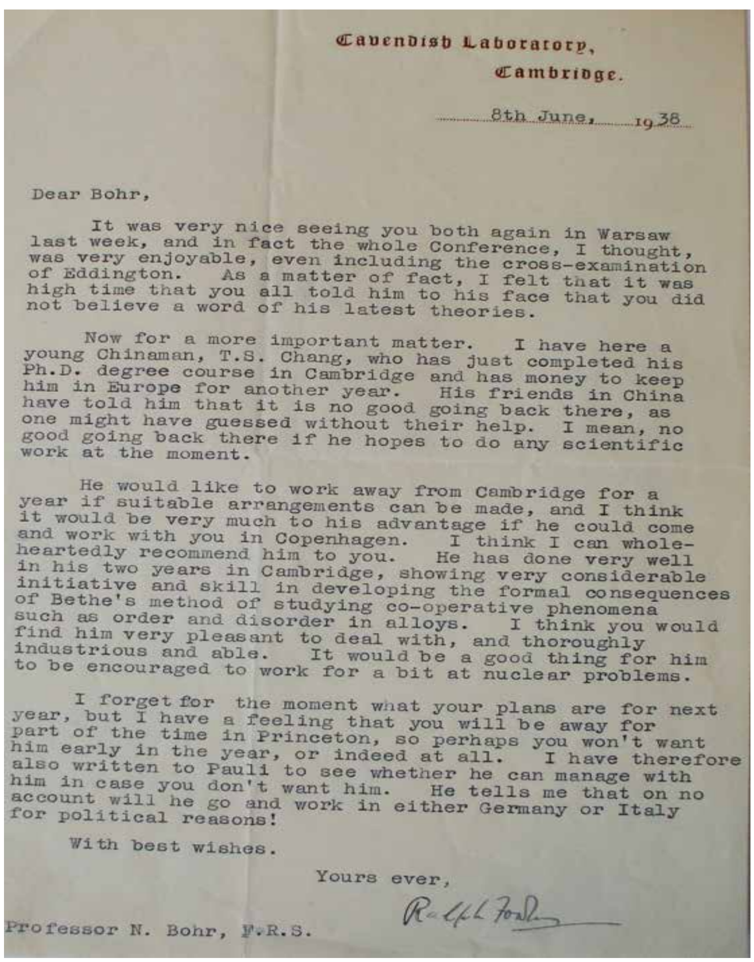
From the literature, we see that two of Chang's papers were suggested by Fowler. The first was to study the anomalous behavior of the specific heat of solids due to molecular rotation. Fowler himself studied this question in 1935. Fowler's method assumes that the molecules rotate under an effective field, essentially the Bragg and Williams approximation. Chang successfully regarded the molecule in the center plus its nearest neighbors as a small group, following Bethe's method. The ignored effect of the rotation of the outer molecules on the small group, was compensated by the effective field of the nearest neighbor molecules in the small group. The results showed the existence of a critical temperature and a discontinuity in specific heat due to the sudden addition of rotational degrees of freedom at the critical point. This gained the attention of his peers. The paper was completed quickly and was submitted in June 1936. At the end of the dissertation he thanked Fowler "for his advice on this problem and for his help in writing the dissertation." This indirectly shows that Chang effectively completed the specific research by himself after determining the topic. Another paper on the statistical theory of adsorption of bimolecular gases onto solids also includes such a thank you note.

One of Chang's characteristics was his quick thinking. Therefore, he was able to use the Bethe method to complete the research suggested by Fowler, and at the same time give full play to his mathematical expertise to further develop the Bethe method.

He extended Bethe's method to include the contribution of the interaction between the next-nearest neighbor lattice points, which significantly improved the degree of agreement between the Bethe theory of the alloy order-disorder phase transition and experiment, and he became the first person to successfully study the next-nearest neighbor approximation. He discussed the ordering properties of binary alloys near the critical point of the superlattice of AB-type alloys and the possibility of the existence of AB3-type superlattices under all component concentration ratios. In analyzing these results, he was acutely aware that these calculations could be directly applied to the adsorption of gases onto solid surfaces. He pointed out that the adsorbed atoms can be regarded as one component of a binary cooperative system, and the regularly arranged unoccupied lattice points in the solid adsorption layer that can absorb gas atoms can be regarded as another component. So the equations and calculation methods of statistical mechanics of this system can be applied to the study of binary alloys, but the physical quantities are changed to the corresponding quantities in the adsorption phenomenon. He applied this method to prove that under certain conditions, in the adsorption layer, superlattices may be formed, becoming the first person to propose the theory that superlattice may be formed in adsorption.

In statistical mechanics, the standard way to study the properties of a physical system in equilibrium is to construct the system's partition functions (or macropartition functions), and then directly derive the properties of the equilibrium from these functions. Therefore, it is of fundamental importance to give a partition function. Bethe's method does not involve the partition function directly, but uses some indirect methods to calculate the equilibrium properties of the system. Chang thought that since Bethe's method gives the equilibrium property, it could be reversed to derive the corresponding partition function. Here, the key is to ask for the number of configurations in the expression for the partition function. Chang first took the adsorption problem as an example, comparing the equilibrium properties obtained by Bethe's method with those given by the macropartition function, and he derived the relevant expressions. Later, a variety of more complex situations were considered. These formulas for configuration numbers are called "Chang's Combinatory Formulas". With the macropartition functions obtained in this way, one can apply them to derive various properties of the system. An important result was a proof that the Bethe approximation is completely equivalent to the quasichemical method.

These works of Chang



Cavendish Laboratory,
Cambridge.

8th June, 1938

Dear Bohr,

It was very nice seeing you both again in Warsaw last week, and in fact the whole Conference, I thought, was very enjoyable, even including the cross-examination of Eddington. As a matter of fact, I felt that it was high time that you all told him to his face that you did not believe a word of his latest theories.

Now for a more important matter. I have here a young Chinaman, T.S. Chang, who has just completed his Ph.D. degree course in Cambridge and has money to keep him in Europe for another year. His friends in China have told him that it is no good going back there, as one might have guessed without their help. I mean, no good going back there if he hopes to do any scientific work at the moment.

He would like to work away from Cambridge for a year if suitable arrangements can be made, and I think it would be very much to his advantage if he could come and work with you in Copenhagen. I think I can wholeheartedly recommend him to you. He has done very well in his two years in Cambridge, showing very considerable initiative and skill in developing the formal consequences of Bethe's method of studying co-operative phenomena such as order and disorder in alloys. I think you would find him very pleasant to deal with, and thoroughly industrious and able. It would be a good thing for him to be encouraged to work for a bit at nuclear problems.

I forget for the moment what your plans are for next year, but I have a feeling that you will be away for part of the time in Princeton, so perhaps you won't want him early in the year, or indeed at all. I have therefore also written to Pauli to see whether he can manage with him in case you don't want him. He tells me that on no account will he go and work in either Germany or Italy for political reasons!

With best wishes.

Yours ever,

Professor N. Bohr, F.R.S.

Figure 1 Fowler's letter of recommendation to Niels Bohr, June 8, 1938 show that he had the courage to put forward new ideas and give full play to his strengths while quickly completing the research suggested by Fowler, thus completing important work with distinctive features. These papers end by thanking Fowler for being "interested," which is not merely polite. Fowler's admiration for his work is clear from the fact that it took Chang only two years to get the Ph.D. that others take three or four years to get. In addition, there are more than ten substantial references to Chang's work in the famous book "Statistical Thermodynamics" by A. Guggenheim (1901-1970) and Fowler, which was subsequently published, and there is a special section that describes "Chang's Combinatory Formula" [11]. This is also the first time that the achievements of Chinese statistical physicists have been cited in an internationally renowned monograph or textbook.

On October 25, 1938, Chang received his Ph.D [12], and together with Wang Jwu-Shi (王竹) who went to Cambridge to study a year earlier than him, they acquired the earliest doctorates in statistical physics in China. Mr. Wang Jwu-Shi was a graduate student under the actual supervision of Dr. John Keith Roberts (1897-1944) but under Fowler's name [13], and he was also one of the pioneers of statistical physics research in China. Fowler guided the start of statistical physics research in China in this unique way.

The funds of the Boxer indemnity for UK were awarded for three years. After Chang obtained his doctorate in two years there was still one year of funding available. He wanted to make good use of this circumstance, so while continuing to study statistical mechanics, he expanded his attention to the study of quantum field theory and particle physics (then called "elementary particle physics" and classified as "nuclear physics"). His plan was strongly supported by Fowler, and on June 8, 1938, Fowler wrote to recommend him to Niels Bohr (Figure 1). The letter read: "I think I can wholeheartedly recommend him to you. He has done very well in his two years in Cambridge, showing considerable initiative and skill in developing formal consequences of Bethe's method of co-operative phenomena such as the order and disorder in alloys. I think you would find him very pleasant to deal with, and thoroughly industrious and able. It would be a good thing for him to be encouraged to work for a bit at nuclear problems." [14] Bohr responded quickly and welcomed him.

Niels Bohr, C. Møller, P. A. M. Dirac, Aage Bohr and T. S. Chang

In October 1938, Chang arrived at the Institute of Theoretical Physics, University of Copenhagen, Denmark, and was warmly welcomed by Bohr. Bohr asked him to live in his home. C. Møller, who was famous for deriving the electron-electron Müller scattering cross section, was engaged in fundamental particle theory research at Bohr's institute at that time. Also present was L. Rosenfeld, who made important contributions in the early research in quantum electrodynamics and later proposed the term "lepton". Wick, who is famous for his Wick theorem in quantum field theory, was also there, as were many others (Fig. 2). Bohr arranged for Møller to guide Chang. When Bohr visited Princeton in February, 1939, he recommended him to work with W. Pauli at the Swiss Federal Institute of Technology in Zurich. In Zurich, he also met M. Fierz, famous for deriving the Fierz transformation in quantum field theory. Chang once again showed a strong ability to enter new fields. In just nine months, he completed two papers which were sent to Bohr and Møller in June [15]. The problem addressed in the papers revolved around the hot theme at the time – the Yukawa particle.

The first paper, "The azimuthal dependence of processes involving mesons" was originally intended to study the interaction of Yukawa particles with electric fields. Since the Yukawa particle was a vector particle in physicists' minds at that time, the meson in this article is a vector particle. Interestingly, soon after Chang arrived in Zurich, Pauli told him to pay attention to the relationship between spin and azimuth in elastic scattering, and claimed that it was easy to calculate. Chang didn't think so, and wrote to Møller that he felt the task to be "very difficult and needed a real effort". But in fact, he completed it very quickly [16]. The paper discusses the angular distribution of elastic scattering and the process of radiating quanta for the case of arbitrary polarization, modified with the help of Møller and Rosenfeld, and sent to the Proceedings of the Cambridge Philosophical Society with Bohr's consent [17].

Another paper on "Properties of mesons described by a pseudo-scalar wave functions" includes formulas for the scattering of pseudoscalar mesons by electrostatic fields, absorption and emission of photons by nucleons, scattering by nucleons, and beta decay lifetimes. At the time, no particles had been identified as pseudoscalar mesons, so this article was actually directed towards the discovery of new particles. At that time, Chang did not realize that this article was very useful, and the publication process was very tortuous. This is entirely due to the timing. At that time in China, Japan had already occupied Nanjing on December 13, 1938. Beijing, where Chang's parents and younger sister were located, had already fallen, and it was impossible for him to return to Beijing. Chang hoped to continue working in Copenhagen for a period of time, and Bohr very much supported his wish. On the one hand, Chang applied for Danish funding, and at the same time, he applied to the Rockefeller Fund following Bohr's suggestion [18]. But since the latter supported experimental work, he told Bohr that it might be difficult for him to be selected. By the second half of the year, both applications are known to have failed. Bohr had offered to help him apply for the funding from Denmark, but the situation in Europe changed dramatically, with World War II looming. Bohr wrote in a letter to Chang: "...everything is very difficult in the current tense situation, and no one is sure what will happen in the future, which is why I have not replied to your letter. Because I do not know what advice to give you and what kind of help I can give you in a critical

Figure 2: Group photo of all members of the Bohr Institute in October 1938. The first seated person from the right is Chang. N. Bohr is the sixth from the right. Møller is third from the right and Wick fourth from the left.

Continued from page 7

situation" [19]. Before this letter was sent, Bohr revised it several times, reflecting Bohr's preoccupation and hesitation, and the facts proved that Bohr's judgment was correct.

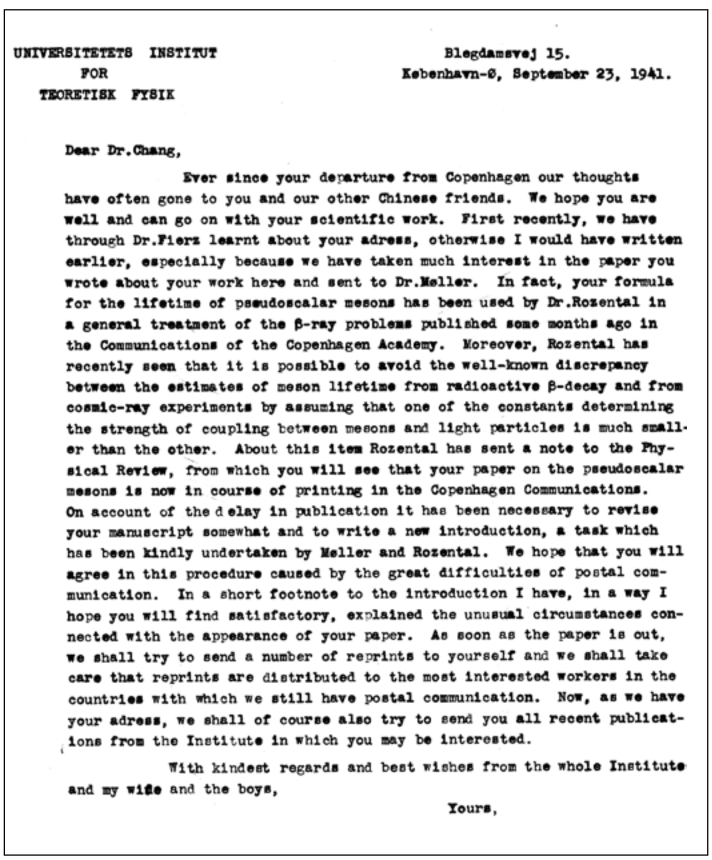
On September 1, 1939, the outbreak of World War II made it impossible for Chang to return to Copenhagen to work for a while. At that time, it was impossible to return to Denmark from Switzerland. Since he had received an invitation from the Department of Physics of Chongqing Central University to hire him as a professor in April 1939 [20], he returned to China by boat from Marseille, France in October, stopped in Shanghai first, and then passed through Vietnam, Kunming, then arriving at Chongqing Central University. Subsequently, Denmark was also occupied by the fascists. Bohr's contact with him was cut off, and the paper was not published immediately. In 1941, Rozental of the Bohr Institute was studying the problem of the 'muons' discovered in the famous cosmic rays. Previous studies on this issue had considered vector mesons, but Rozental used the pseudo-meson lifetime formula derived by Chang to discuss the possibility of whether they were pseudo-standard mesons. Bohr attached great importance to Chang's paper and thought it should be published immediately, but Chang could not be contacted, and the time was two years late, so he asked Møller and Rozental to write a new introduction for the paper with some necessary revisions, and Bohr himself wrote a footnote explaining the situation, to be published in "Royal Danish Academy of Sciences, Mathematics-Physics Journal"(Kongelige Danske Videnskaberrnes Selskab. Matematisk-fysiske Meddelelser). During the printing period, Bohr learned Chang's contact information from Fierz, so on September 23, 1941, he wrote a letter to tell Chang in detail about the process described above, and said that a copy of this article would be sent to relevant scientists from all countries with postal correspondence with Denmark (Figure 3) [21]. Chang's paper "Properties of mesons described by a pseudo-scalar wave functions" played a role in such a tortuous way, and Bohr's deep concern was touching.

On September 23, 1941 Bohr spoke highly of Chang's work. In his letter of recommendation (Figure 4), he wrote: "As well through letters from Professor Fowler in Cambridge where Dr. Chang worked before he came to Copenhagen, as through personal contacts with my collaborators and myself during his stay in this Institute for the last six months, I have indeed learned most highly to appreciate his scientific and personal qualifications. Besides concluding the investigation on problems of statistical mechanics carried out in Cambridge under the direction of Prof. Fowler, he worked in Copenhagen, especially under the direction of Prof. Møller, on various problems arising out of the recent developments in nuclear theory, especially as regards phenomena connected with beta-ray disintegrations. In this work, which is nearing its completion, Dr. Chang showed a quite unusual quality as well in mastering the new intricate mathematical methods involved as in grasping their physical implications most thoroughly. His enthusiasm and keen insight in problems of theoretical physics permit in fact to entertain great expectations as to his future scientific activity, and if, after the continuation of his studies under Prof. Pauli in Zürich during my absence from Copenhagen this term on a journey to America, he wishes to return to this Institute, he will be very welcome indeed." [22]

During Chang's six months in Denmark, he had also established a deep friendship with the Bohr family because he had been living in the Bohr home, also with Bohr's children, and they had become friends. This included Aage Bohr (1922-2009), 1975 Nobel Prize winner in physics, who was a few years younger than him. (He is often called "Little Bohr" in China.) Among the 19 correspondences between Chang and Bohr's family found in the Niels Bohr Archives, 5 are correspondences between Chang and Bohr's wife Margrethe Nørlund (1890-1984), of which 4 are dated in 1939 from September to October. Chang wrote them while he was preparing to return to China. The luggage he left at Bohr's house was shipped by Margaret to his eldest brother Chang Zongbing (张宗炳), in Shanghai at that time [23].

In 1945, Chang visited Europe for the second time. After he arrived in England, he wrote to Bohr immediately, eager to learn about the research work of Bohr, Møller and Rosenfeld [24]. Bohr's reply was like that of a family member, expressing his "great pleasure" that Chang had "come safely through the hard times and are now again in England working with Dirac". He also wrote that they "will have an annual conference on actual atomic problems where we used to see a number of old friends, and to which we are hope that we shall also soon have the pleasure of seeing you." Speaking of family, he wrote "We are all well and happy to be united again after the long separation during the last years of the war. We all send you our best heartiest greetings and best wishes." [25]

In 1958, when the scientific exchanges between the West and China were completely interrupted, Niels Bohr first discussed with Chen-Ning Yang (杨振宁) and Tsung-Dao Lee (李政道) about inviting Chinese



UNIVERSITETETS INSTITUT FOR TEORETISK FYSIK

Blegdamsvej 15.
København-Ø, September 23, 1941.

Dear Dr.Chang,

Ever since your departure from Copenhagen our thoughts have often gone to you and our other Chinese friends. We hope you are well and can go on with your scientific work. First recently, we have through Dr.Fierz learnt about your adress, otherwise I would have written earlier, especially because we have taken much interest in the paper you wrote about your work here and sent to Dr.Møller. In fact, your formula for the lifetime of pseudoscalar mesons has been used by Dr.Rozental in a general treatment of the β-ray problems published some months ago in the Communications of the Copenhagen Academy. Moreover, Rozental has recently seen that it is possible to avoid the well-known discrepancy between the estimates of meson lifetime from radioactive β-decay and from cosmic-ray experiments by assuming that one of the constants determining the strength of coupling between mesons and light particles is much smaller than the other. About this item Rozental has sent a note to the Physical Review, from which you will see that your paper on the pseudoscalar mesons is now in course of printing in the Copenhagen Communications. On account of the delay in publication it has been necessary to revise your manuscript somewhat and to write a new introduction, a task which has been kindly undertaken by Møller and Rozental. We hope that you will agree in this procedure caused by the great difficulties of postal communication. In a short footnote to the introduction I have, in a way I hope you will find satisfactory, explained the unusual circumstances connected with the appearance of your paper. As soon as the paper is out, we shall try to send a number of reprints to yourself and we shall take care that reprints are distributed to the most interested workers in the countries with which we still have postal communication. Now, as we have your adress, we shall of course also try to send you all recent publications from the Institute in which you may be interested.

With kindest regards and best wishes from the whole Institute and my wife and the boys,

Yours,

Figure 3 Bohr's correspondence to Chang on the publication of the paper " Properties of mesons described by a pseudo-scalar wave functions " physicists to the Bohr Institute. Then Aage Bohr wrote to Chen-Ning Yang, expressing their hope to invite Chinese senior physicists for short-term visits and young physicists for one-year visits at the Bohr Institute. The Aage Bohr letter identifies certain Chinese physicists, especially Chang: "We also know, from the period just before the war, T. S. Chang, of whom we have a very favourable impression. I think he spent a number of years in the United States, but that he is now back in China " [26] Yang replied and recommended three Chinese physicists: "T. S. Chang, Hu Ning (胡宁), and Peng Huanwu (彭桓武) are all good candidates." Yang also proposed Huang Kun (黄昆) [27]. However, due to the complexity of the political situation, in the end only the visit of young physicists was realized.

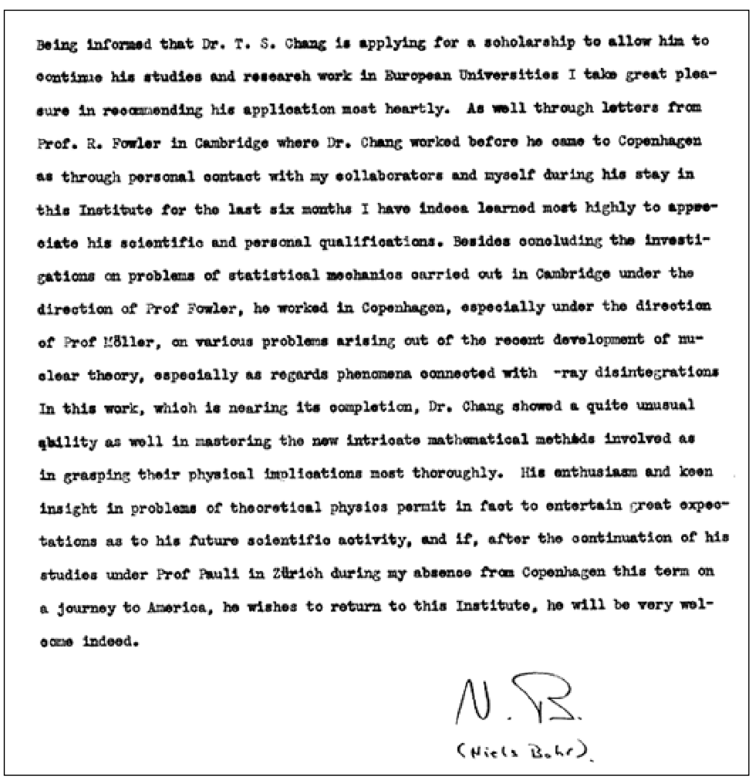
In 1962, Aage Bohr and his wife visited China for the first time [28]. (The second time was in 1973.) Aage Bohr asked to see Chang, and they spoke freely when they met. Chang was originally a very straightforward person. He said whatever he thought. For example, he said: "The living standard of the Danes is high, and all problems are solved when the living standard is high." It is said that Mrs. Aage Bohr asked him how many cloth tickets he had. He didn't know, so he said a sufficient number. When he went home and asked his wife, and found the numerical difference was quite large, he went to the hotel again to correct it for Aage Bohr's wife. What he did violated the rule not to see foreign guests privately. These inappropriate words and deeds made him almost unable to attend the banquet of the Danish ambassador. Regarding the invitation of the ambassador, there was an instruction that "it needs to be considered, such as Prof. T. S. Chang. It's better not to show up again." [29], but he was finally allowed to participate. Interestingly, little Bohr proposed a nuclear theory research topic in his lecture, and the Institute of Atomic Energy handed it over to Zhang Zongsui's younger sister Zhang Zongye (张宗烨), who finally completed it and published it in Acta Physica Sinica. It also became a good story.

P. A. M.Dirac and T. S. Chang

During the Anti-Japanese War, under very difficult conditions, Chang insisted on undertaking research in statistical physics and quantum field theory at Chongqing Central University. He completed 7 papers in a very isolated situation. He was eager to communicate with high-level scientists in the direction of the quantization of constrained systems, which he had been working on since 1944. This goal was realized with the help from the Sino-British Cultural Association. As one of the three professors sponsored by the association that year, he visited Cambridge University to give lectures as a senior researcher from January 1946 to September 1947. He had been invited by Dirac. (Dirac and Chang had both been students of Fowler, and they were in this sense brothers. But when Chang was studying for a his doctorate in Cambridge from 1936 to 1938, Dirac was already a famous professor. He had received his doctorate from Cambridge University in 1926, and he had won the Nobel Prize in Physics for establishing the Dirac equation in 1933.

Dirac was mild-mannered and taciturn, with deep thoughts and clear and concise logic. He liked to think alone, and some memoirs report that he was not easy to approach [30]. However, Chang got along well with him. They often ate together, played chess, and discussed physics. In 1947 Dirac went to the Institute of Advanced Studies in Princeton as a visiting researcher, and he invited Chang to join him. They worked together at Princeton for half a year. Prior to that, in the autumn of 1946, Dirac had invited Chang to teach the course "Quantum Mechanics of Fields" at Cambridge University, and Chang accepted. In the annual report of Cambridge University from 1946 to 1947, the course name, time, classroom and teacher name of T. S. Chang were all clearly recorded [31]. This is the first time Chinese people have lectured at Cambridge University. This period was another important stage in Chang's academic career. He would go on to make important achievements in the regular quantization of constrained field systems.

The earliest constrained field system that people had faced that needed to be quantized was the electromagnetic field. Dirac, Heisenberg, Fermi and Pauli had proposed some methods to make the quantization of the electromagnetic field possible, but they were not all totally satisfactory. Dirac was one of the first to study more general systems with various types of constraints from a theoretical point of view. In his 1933 article he tried to use indefinite multipliers to write the Hamiltonian form of a constrained system. (In 1930, when L. Rosenfeld quantized the electromagnetic field, he also used an arbitrary space-time function multiplier, but Chang did not know this work). Chang was the first to point out that the existence of these multipliers brought problems to quantization. He found that there are different types of constraints that require different solutions. He pointed out that for a class of systems, the constraints are equivalent to eliminating some canonical degrees of freedom. He proved that in this type of model, the function multiplied by the constraints can be related to the dynamical variables and be nontrivial when quantized. This is actually what Dirac later called constraints of the second class. The other category is classical gauge theory. Chang first proposed the form which such theories take. If there are arbitrary space-time functions, there


Being informed that Dr. T. S. Chang is applying for a scholarship to allow him to continue his studies and research work in European Universities I take great pleasure in recommending his application most heartly. As well through letters from Prof. R. Fowler in Cambridge where Dr. Chang worked before he came to Copenhagen as through personal contact with my collaborators and myself during his stay in this Institute for the last six months I have indeea learned most highly to appreciate his scientific and personal qualifications. Besides concluding the investigations on problems of statistical mechanics carried out in Cambridge under the direction of Prof Fowler, he worked in Copenhagen, especially under the direction of Prof Møller, on various problems arising out of the recent development of nuclear theory, especially as regards phenomena connected with -ray disintegrations In this work, which is nearing its completion, Dr. Chang showed a quite unusual ability as well in mastering the new intricate mathematical methods involved as in grasping their physical implications most thoroughly. His enthusiasm and keen insight in problems of theoretical physics permit in fact to entertain great expectations as to his future scientific activity, and if, after the continuation of his studies under Prof Pauli in Zürich during my absence from Copenhagen this term on a journey to America, he wishes to return to this Institute, he will be very welcome indeed.

N. B.

(Niels Bohr)

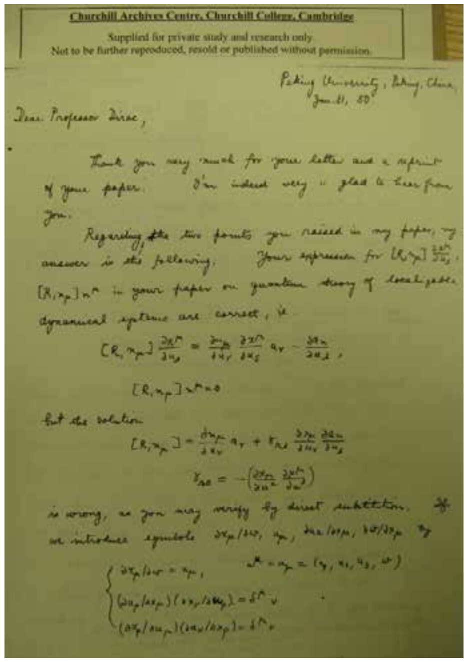
Figure 4 Bohr's letter of recommendation for Chang, January 23, 1939

Continued from page 9

would be problems with quantization, and he proposed a preliminary solution. He developed quantization techniques applicable to a class of covariant gauge models that were broader than the electromagnetic field case, and proposed schemes to treat the gauge conditions not as operator equations, but as initial conditions imposed on states. Chang made significant contributions to the canonical quantization of constrained systems [32] [33]. In addition, he became one of the earliest investigators of quantum theory involving higher-order derivatives, and he more systematically derived the canonical forms of the equations of motion, established gauge-invariant expressions for the fluid energy-momentum tensor, the angular momentum tensor, and the symmetric energy-momentum tensor, in which he applied his method of quantization of constrained systems. These results of Chang were discussed with Dirac or recommended by Dirac for publication.

After Chang returned to China, he still communicated with Dirac. It is a pity that, after so many years, especially during the "Cultural Revolution", there is no information about contacts with foreign scientists at his home. However, we found a few years ago four letters from Chang to Dirac in Cambridge, dated September 18, 1949, January 31, 1950, February 1, 1950 and September 13, 1950. The letters clearly indicated the characteristics of their getting along - straight to the point, and mainly discussing specific physical issues.

In the letter of September 18, 1949, he wrote: "Dear Professor Dirac: Perhaps you will be glad to hear that life is returning to normal in this part of the world and one may sit down again to work. In the last two months, I have written a short paper which develops your theory of quantum mechanics of localizable dynamical systems, and shows that it is not much larger than the Weiss theory"..." He then informed Dirac that he enclosed a manuscript of a paper. He added: "As there are no regular mailings between this part of the world and the rest since February (and thus no journals reach us since that time), I have not been able to learn what has happened in physics since February. This is most unpleasant, and I hope that this situation would not last long" He asked Dirac "If by any chance you may send me through the British Council some papers worthy of studying ", and finally he asked: "How are conditions with


Churchill Archives Centre, Churchill College, Cambridge

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Peking University, Peking, China
Jan. 31, 50

Dear Professor Dirac,

Thank you very much for your letter and a reprint of your paper. I'm indeed very glad to hear from you.

Regarding the two points you raised in my paper, my answer is the following. Your expression for [illegible] in your paper on quantum theory of localizable dynamical systems are correct, i.e.

[illegible]

but the solution

[illegible]

is wrong, as you may verify by direct substitution. If we introduce symbols [illegible]

[illegible]

Figure 5 Chang 's letter to Dirac dated January 31, 1950

you? In what are you now interested? Have you made any new approach toward solving the difficulties in quantum electrodynamics?" [34].

The letter dated January 30, 1950, was entirely devoted to discussing specific physical problems. He bluntly stated that one of the formulas in the article Dirac sent him was wrong (Fig. 5) [35] However, the next day, he wrote to Dirac again, saying that he was wrong, that both of their formulas were correct, and that he had misunderstood the previous day the symbols Dirac had used. The letter dated September 12, 1950, was also entirely a matter of Chang seeking Dirac's opinion on a newly written article, and also asking whether he could submit a manuscript to a Western journal. [36]

Such communications soon ceased completely. Because the "Thought Remolding Movement" in 1952 happened, Chang was criticized, including the fact that he published articles in western journals after his liberation.

Joseph Needham and T. S. Chang

Chang went abroad to Cambridge and to the United States for the second time with funding support from the Sino-British Cultural Association, thanks to the help of a very important figure in the history of scientific and cultural exchanges between China and the United Kingdom – Joseph Needham.

Joseph Needham (1900-1995), was master of "History of Science and Technology in China", a member of the Royal Society, a Fellow of the British Academy (FBA), and an honorary director of the Needham Research Institute in Cambridge University. In 1950, he personally initiated and became the president of the China-Britain Friendship Association. In 1954 Needham began to publish his masterpiece "Science and Civilisation in China", which caused a sensation, and he was known as "a great scholar of the 20th century" and "an encyclopedic figure". In 1994 he was selected among the first batch of foreign academicians of the Chinese Academy of Sciences. From 1943 to 1946, Needham came to China and established the Sino-British Science Co-operation Bureau under his suggestion. He had many contacts with people from the cultural and scientific circles, including T. S. Chang, Chang's father Zhang Dongsun (张东荪), and his elder brothers Zhang Zongbing (张宗炳).[37][38].

Needham had the habit of recording names, and the card that recorded T. S. Chang: 張宗燧, read "CHANG Tsung-sui- Math. physicist, Chungyang Ta. 2 papers sent for him to Fowler met @ Ox & Camb. Dinner" (meaning: T. S. Chang is physicist at Central University，I sent his 2 articles for Fowler. Met him at Oxbridge and Cambridge for Dinner). Since Fowler died in 1944, it can be assumed that this card was written in 1943-44. It follows that "meeting at Oxbridge" means they met between 1936-38. In his diary on October 25, 1944, he recorded a lunch with T. S. Chang [39]. Needham recommended three professors to the Sino-British Cultural Association supporting them to visit the UK in 1945-46, and one of them was Chang. From 1945 to 1947, the Sino-British Cultural Association assisted in sending 138 papers of Chinese scholars during the war to western journals for publication, including 21 papers in physics [40], of which Chang accounted for 6 papers. After Chang came to England, his academic exchange with Dirac was very successful. Later, as we have seen, Dirac was going to Princeton and invited Chang to go with him. Introduced by Dirac, the Institute for Advanced Study in Princeton invited Chang to make a short-term visit as a researcher. Chang made a proposal to the Sino-British Cultural Association hoping that it could be extended by one year [41], but the request made by the Sino-British Cultural Association made it difficult for Chang. Needham immediately contacted the British Council in London when he discovered this. He suggested that Chang send a telegram to Wu Youxun (吴有训), then president of Central University, as soon as possible, asking them to contact the British Council [42]. Chang followed Needham's advice and things were settled satisfactorily, heading to America with Dirac as scheduled.

After the victory of the Anti-Japanese War, China considered the development of atomic energy. Some scientists thought that the relevant first-class physicists should be brought together. In 1947, Hu Shi(胡适), the president of Peking University, wrote to the government to propose the establishment of the Center for Atomic Physics at Beijing University. The letter listed the names of nine physicists at home and abroad, including Chang, and indicating that he was in Cambridge at that time and had agreed to go to Beijing University [43]. On September 24, 1947, the day before he left for the United States from Cambridge, Chang wrote a letter to Needham's wife to say goodbye and thank her for taking care of him. The letter said: "I now aspire to serve my country in some way that is less about teaching and more about real life. But seriously, nine times out of ten, I'll find myself still in a university. Although I will not hesitate to leave the university whenever the time comes, but until this happens, I will stay to teach and do research." [44]. We feel that what Chang wrote here is an implicit reference to the Center for Atomic Physics. Most of the nine scientists mentioned in Hu Shi's letter later participated in China's atom bombs, missles, and artificial satellites research, but Chang did not. However, it is interesting that Yu Min(于敏), Chang's first postgraduate student after returning to Beijing University, made a significant contribution to China's hydrogen bomb research.

After the end of 1950, Chang's contact with his western scientist friends ceased. Here, there is a small matter related to foreign friends that should be mentioned. During the 1952 "Thought Remolding Movement(思想改造运动)", Chang was criticized at Beijing University. Afterwards, he was transferred from Beijing University to the Beijing Normal University. He was not happy with this. It was not until later that L. Infeld, the president of the Polish Academy of Sciences and a famous theoretical physicist, visited Beijing. He expressed surprise to the receptionist upon learning that Chang had been transferred to Beijing Normal University. Infeld was of the opinion that such an outstanding scientist should not be working there. The receptionist made a truthful report which led to his full transfer to the Institute of Mathematics of the Chinese Academy of Sciences in July 1956.

Conclusion

In the initial stage of China's establishment of modern physics research, a group of pioneers of related research in China played a very important role in learning and exchanging with top international scientists. Chang's contacts with world-renowned scientific masters were outstanding in terms of number, closeness, and effect - leaving an unforgettable story in the history of Sino-foreign exchanges in physics research.

During the "Cultural Revolution", Chang's family suffered great misfortune. The younger brother Zhang Zongjie (张宗颎) and his brother's wife both committed suicide. And the father was arrested and died in prison. T. S. Chang committed suicide on June 30, 1969 by taking an overdose of sleeping pills, at the age of 54, and this is extremely regrettable. After the "Cultural Revolution" he was completely rehabilitated and a memorial service was held. In 2005, a fairly large-scale "Mr. T. S. Chang's 90th Anniversary Meeting" was held, and everyone gathered to talk about his contributions and cherish his demeanor. This year, "Modern Physical Knowledge" published a commemorative issue. Here, we hope to express our heartfelt remembrance to T. S. Chang once again through this article published in "Physics".

Acknowledgments

Thanks to Churchill Archives, Cambridge University Archives, East Asia Library, Niels Bohr Archives, and the Archives of the Chinese Ministry of Foreign Affairs for their permission to consult relevant archives.

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