赵忠尧论文选集

SELECTED WORKS OF ZHAO ZHONGYAO

科学出版社

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《赵忠尧论文选集》编辑委员会　编

EDITED BY

THE EDITORIAL COMMITTEE OF
SELECTED WORKS OF ZHAO ZHONGYAO

科 学 出 版 社
SCIENCE PRESS
1 9 9 2

Responsible Editor: Rong Yumin

Published by Science Press
16 Donghuangchenggen North Street
Beijing 100707, China

Printed in Beijing

ISBN 7-03-002958-5/ O · 547

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序　言

赵忠尧教授是我国著名的物理学家，是我国原子核物理、中子物理、加速器和宇宙线研究的先驱者和奠基人之一。

赵忠尧教授生于 1902 年， 1925 年从东南大学毕业后任清华大学助教。1927 年去美国加州理工学院，从师于诺贝尔奖金获得者密立根 (R.A. Millikan) 教授。1930 年获得哲学博士学位。 1929 年他和英、德的几位物理学家同时独立地发现了当硬 γ 射线通过重元素时，除了康普顿散射和光电效应引起的吸收外，还存在着反常吸收。为进一步研究反常吸收机制，他开展了硬 γ 射线散射的研究，并首先观察到硬 γ 射线在铅中还会导致产生一种特殊辐射。这些结果先后发表在《硬 γ 线的吸收系数》和《硬 γ 线散射》的论文中。赵忠尧教授的这些工作，是正电子发现的先驱。二年后，他的同学安德逊 (C.D. Anderson)发现正电子后，人们才认识到他发现的"反常吸收"，实际上是 γ 线在物质中产生电子对的效应；而他发现的"特殊辐射"实际上是首次观察到正负电子对的湮灭辐射。关于赵忠尧教授在对产生和湮灭辐射两方面的重要贡献，最近杨振宁教授专门写了" C.Y. Chao, Pair Production and Pair Annihilation"，(见本选集附录)，对此作了详细的论述。

1931 年他回国后任清华大学物理系教授，在我国首次开设核物理课程，并主持建立我国第一个核物理实验室，开展了《硬 γ 射线与原子核相互作用》和《中子的共振吸收》等方面的研究工作。1937 年抗日战争爆发，赵忠尧教授离开北平，先后到云南大学、西南联大和中央大学任教。在长期的教学活动中，培养了一批以后为我国原子能事业作出重要贡献的人才。

赵忠尧教授不仅积极从事科学和教育方面的工作，还经常考虑如何利用科学技术迅速发展我国工业的问题。九一八事变后，日本军国主义大举侵略我国，赵忠尧先生感到迫切需要发展民族工业，才能使国家免受欺侮。为此，他自己出钱并在朋友中集资创办了一家铅笔厂，在工艺技术，经营管理等方面克服了许多困难，倾注了许多精力，终于使著名的"长城牌"铅笔问世。

抗战胜利后，赵忠尧教授感到非常有必要在国内建立设备较好的核物理实验室。1946 年他受当时政府的委派赴比基尼群岛参观美国的原子弹试验；之后又在美国麻省理工学院、加州理工学院等处进行核物理和宇宙线方面的研究。这期间他化了巨大精力在美国设计、订购静电加速器的各种零部件，购买了一些探测器和电子仪器，并定制了一套多板云雾室。

中华人民共和国成立后，1950 年他冲破重重困难，毅然回国。当他经过日本时，受到当时在日本的美国占领军总司令麦克阿瑟 (MacArthur) 的无理扣留。那时国民党也派专人前往日本动员他去台湾，但他坚决要回到新中国。经我国政府的积极营救和全国广泛的舆论压力，美方不得不把他放行。他回到新中国时受到全国广大人民和科技界的热烈欢迎。

他在回国时曾带回当时国内尚无条件制备的上述加速器部件和实验设备。回国后参与中国科学院近代物理研究所的创建，主持建立了核物理研究室。利用带回的加速器部件先后于 1955 和 1958 年建成了我国最早的 70 万伏和 200 万伏高气压型的质子静电加速器，为我国核物理、加速器和真空技术的研究打下了基础。

赵忠尧教授 1956 年任中国科学院物理研究所副所长， 1958 年任原子能研究所副所长，并具体领导和参加了核反应的研究，为开创我国原子核科学事业作出重要贡献。1972 年他参与高能物理研究所的筹建工作，1973 年任副所长一直到 1984 年。赵忠尧教授多年来兢兢业业为发展我国核物理和高能物理研究事业、为培养我国原子能事业和核物理、高能物理的研究人才做出了很大的贡献。这期间，赵忠尧先生还多次向有关部门提出了发展我国科学事业的许多具体建议。

赵忠尧教授在教育事业方面有很大贡献，三四十年代先后在国内很多知名大学担任教授，五十年代后期又为中国科技大学创办近代物理系，在师资队伍、实验室建设、教学质量等方面都下了很大功夫。他还亲自讲授《原子核反应》专业课。使科技大学近代物理系培养的学生不仅基础知识札实，而且热爱实验，肯于动手，不怕艰苦。六十多年来，赵忠尧教授培养的学生很多已成为知名的物理学家及四化建设的骨干力量。

赵忠尧教授 1948 年当选为中央研究院院士， 1955 年受聘为中国科学院数理化学部学部委员。他曾担任中国物理学会副理事长，现在是名誉理事；他还担任中国核学会的名誉理事长。自 1954 年第一届全国人民代表大会起一直担任全国人大代表；1964 年起当选为第三、四、五、六届全国人民代表大会常务委员会委员。

赵忠尧教授和我是在 1902 年同年出生的，早在 20 年代在美国加州理工学院做研究生时就是同学，返国后在清华大学、昆明西南联合大学又长期同事，彼此之间建立了深厚的友谊。新中国一成立，他就立刻决定返国，这是他热爱祖国的具体表现。他不仅学问精深，而且平易近人，深受同事和学生们的爱戴。《赵忠尧选集》的出版可谓众望所归。从这本文集中，读者可以感受到他严谨的治学态度，领略到他一丝不苟的研究风格。他，是我们广大科技工作者学习的榜样。

周培源

1989 年 10 月 2 日

Preface

Professor Zhao Zhongyao (C.Y. Chao), a famous Chinese physicist, is one of the pioneers and founders of China's nuclear physics, neutron physics, accelerators, and cosmic ray researches.

Professor Zhao was born in 1902. After graduating from the Southeastern University in 1925, he joined Qinghua University as an assistant. He became later a student of Professor R.A. Millikan, Nobel prize winner, in California Institute of Technology (C.I.T.), U.S.A. in 1927 and received his Ph.D. in 1930. In 1929, he and several English and German physicists independently found that when hard γ —rays pass by the heavy element, there exists an abnormal absorption in addition to the Compton scattering and the absorption caused by the photoelectric effect. In order to further study the abnormal absorption, he studied the hard γ—rays scattering and first observed the special radiation induced by the hard γ—rays in lead. These results, which pioneered the discovery of positrons, were published in his articles "Absorption Coefficient of Hard γ— Rays" and "Hard γ — Rays Scattering". Two years later, C.D. Anderson, his schoolmate, discovered the positron, and people realized that Zhao's "abnormal absorption" is just the electron—positron pair production induced by the γ rays in matter and that his "special radiation" is, then, the first observed annihilation radiation of the electron—positron pair. For Professor Zhao's important contributions to both pair production and annihilation, Professor C.N. Yang has a detailed exposition in his recent article "C.Y. Chao, Pair Production and Pair Annihilation" (see Appendix).

In 1931, Professor Zhao returned to China and joined the Department of Physics,Qinghua University as a professor. He first offered lectures on nuclear physics, directed and established the first nuclear physics laboratory, and developed researches on the 《Hard γ ray nucleus interaction》 and 《Neutron resonance absorption》 in China.In 1937, when the War of Resistance Against Japan broke out, Professor Zhao left Peiping and taught in Yunnan University, and afterwards, in the Southwest Associated University and the Central University. During his teaching period, he fostered a large number of scientists and engineers who were to make important contributions to China's atomic energy cause later.

Professor Zhao has not only been assiduously engaged in research work and teaching job,but also has considered how to quickly develop Chinese industries by virtue of science and technology. After the Sept. 18 Incident, which set off the Japanese militarist invasion of China, Professor Zhao thought that the only way our country can avert the bullying was to develop the national industry. Thus, he founded a pencil factory with his own money and funds collected from his friends. He put all his energies into overcoming many difficulties encountered in technology, management and administration, and finally, succeeded in bringing out the famous "Great Wall" pencils.

After we won the War of Resistance Against Japan, Professor Zhao thought that it was the time to establish a well—equipped nuclear physics laboratory in China.In 1946, the Chinese government at that time appointed him to watch the U.S. atomic bomb experiment at Bikini Island. Then, he went to MIT, CIT, and some other places to carry out researches in nuclear physics and cosmic rays. During this period, he spent extraordinary energy in USA, designing and ordering various parts for electrostatic accelerators, purchased some detectors and electronic equipment, and had a multilayer cloud chamber custom—made.

After the founding of the People's Republic of China Professor Zhao surmounted numerous difficulties and resolutely returned to China. When he passed by Japan, he was unjustifiably detained by MacArthur, the Chief Commander of U.S. Occupation Forces in Japan. Meanwhile, he was lured to go to Taiwan by the special agent of Kuomintang from Taiwan. However, in virtue of his firm decision to return to new China and due to the rescue measures vigorously organized by the Chinese government and the pressure of the public opinion from the various circles in China, the U.S. government had to release him. When he arrived at China, he was warmly welcomed by the broad masses of the Chinese people and the Chinese scientists and technologists.

He brought back the above—mentioned accelerator parts and experimental equipment which could not be made in China at that time. After his return, he participated in the founding of the Institute of Modern Physics, Academia Sinica and took charge of setting up the Division of Nuclear Physics. By using the accelerator parts brought back by him, China built the earliest 700 kV and 2 MV high pressure type proton electrostatic accelerators in 1955 and 1958, respectively. These laid the foundation for the nuclear physics, accelerator, and vacuum technique researches in China.

Professor Zhao was the Deputy Director of the Institute of Physics, Academia Sinica in 1956 and the Deputy Director of Institute of Atomic Energy in 1958, where he led and joined the research on the nuclear reaction and made important contributions to initiating the nuclear science in China. He took part in 1972 in the preparation for the setting up of the Institute of High Energy Physics and was Deputy Director of this Institute from 1973 to 1984. For many years Professor Zhao worked conscientiously and had made great contributions to the developments of researches in nuclear and high energy physics and to the training of competent research investigators in these two fields in our countrry. In this period he also submitted many concrete proposals to various government departments on the development of scientific enterprises in our countries.

Professor Zhao also dedicated himself to education. In the thirties and forties of the 20th century, he was professor in various famous universities in China. In the late fifties, he set up the Department of Modern Physics in University of Science and Technology of China and devoted great effort to the training of the teaching staff, and the improvement of the laboratory facilities and teaching quality. He even taught the 《nuclear reaction》 course himself. Therefore, the students who graduated from this department not only have solid background knowledge, but also love doing experiments, with undaunted spirits. In the past sixty years, many students trained by him have become famous physicists and the backbone of the Four Modernization constructions.

Professor Zhao was engaged as a Member of the Mathematics, Physics and Chemistry Division, Academia Sinica in 1955. He was a Vice President of Chinese Physics Society, and now is an honorary member of the board. He is also an honorary President of the Chinese Nuclear Society. Since the First National People's Congress in 1955, he has always been a deputy to the National People's Congress. He was a Standing Committee member of the Third, the Fourth, the Fifth, and the Sixth National People's Congress from 1964.

Professor Zhao and I were born in the same year, 1902. We were schoolmates when we were studying in the graduate school of CIT in the twenties. After return, we were colleaques in Qinghua University and the Southwest Associated University, Kunming. We have established profound friendship. His decision of returning to China immediately after the foundation of new China has shown that he has a deep love for our motherland. Professor Zhao not only has extensive knowledge and profound scholarship, but also has an amiable character and is easy of approach. All his colleaques and students love and esteem him very much. The publication of "Selected Works of Zhao Zhongyao (C.Y. Chao)" just reflects the people's expectations. From this book, readers can feel his strict scholarship and conscientious and meticulous style of doing scientific research. He is a good model for our scientists and technologists.

Zhou Peiyuan
Oct. 2, 1989

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THE ABSORPTION COEFFICIENT OF HARD GAMMA–RAYS

Thesis by
Chung–Yao Chao
In Partial Fulfillment of the Requirements for
the Doctor Degree of Philosophy

California Institute of Technology
Pasdena, California

1930

SUMMARY

The relation between the frequency of hard radiations and the absorption coefficient is not experimentally well established at the present time. In the following work, the absorption coefficient of γ–rays of ThC$''$ is carefully investigated owing to their homogeneity.

As a result, the observed absorption coefficient of light elements is found to agree fairly well with the theoretical formula of Klein and Nishina. Running from low to high atomic numbers, the absorption per electron is, however, found to increase continuously. This was not noticed before because it was usually covered by the photo–electric absorption of the soft components in a non–homogeneous beam. Futhermore, in some cases emphasis was given to the mass absorption coefficient which is exceptionally high for the hydrogen compounds, consequently the characteristic of the continuous increase of the absorption coefficient per electron was neglected.

In order to interpret this anomalous absorption, several scattering experiments are carried out. The forward scattering can be accounted for by the assumption that all the external electrons behave as if they are free in high frequency radiations around a few x–units. Theoretically the part of the anomalous absorption of heavy elements might be due to the scattering of electrons inside the nucleus or that of tightly bound electrons. The fact that, although such a process does not contribute much scattering in the forward direction its contribution in large scattering angles may become important is also indicated in the experiment.

THE ABSORPTION COEFFICIENT OF HARD GAMMA–RAYS

I. Introduction: The classical theory of the scattering of radiations can only roughly account for the experimental results in the region of relatively long wave–length, like that of soft X–rays. For hard radiations, it departs widely from the observations. A.H. Compton[1] and P. Debye[2], independently, applied the quantum consideration to the problem of scattering. The main conclusions reached then, are the following:

1. The wave–length of the scattered rays should be increased by an amount $\triangle\lambda$ which is given by

$$\triangle\lambda = \frac{h}{mc}(1-\cos\theta) = 24.24(1-\cos\theta)\times 10^{-11}\mathrm{cm} \tag{1}$$

2. The intensity of the scattered rays decreases rapidly as the angle of scattering increases. The following formula was proposed by Compton[3]

$$I_\theta = I_0 \frac{1}{2}\frac{1+\cos^2\theta + 2\alpha(1+\alpha)(1-\cos\theta)^2}{\{1+\alpha(1-\cos\theta)\}^5} \tag{2}$$

where I_0 is the scattering intensity at $\theta = 0$ and $\alpha = h\nu/mc^2$ .The change of wave–length was confirmed very satisfactorily by experiments in the X – ray region. Determination of the intensity distribution of the scattering with X – rays are very difficult to make. On the other hand, observations of the scattered γ – rays have been made and agree approximately with the theory as shown by the experiments of Compton[4], Kohlrausch[5], and Hoffmann[6], but the quantitative agreement is not conclusive, owing to the lack of a homogeneous beam and the low intensity.

In 1925, Dirac[7] worked out a formula for the scattering intensity by the new quantum theory, which is fairly close to that of Compton. After the development of Dirac's theory of spinning electrons, Klein and Nishina[8] worked out a new scattering formula, which is very much different from those of Compton and Dirac for high frequency radiations, but approaches them for moderate frequency. The scattering intensity due to one electron, according to Klein and Nishina, is given by

$$I_\theta = I_0\frac{e^4}{2m^2c^4r^2}\frac{1+\cos^2\theta}{[1+\alpha(1-\cos\theta)]^3}\left\{1+\alpha^2\frac{(1-\cos\theta)^2}{(1+\cos^2\theta)[1+\alpha(1-\cos\theta)]}\right\} \tag{3}$$

The difference between this formula and that of Dirac is due to the second term in the last factor, which is missing in Dirac's formula. Now, by integrating over all directions and multiplying by the number of free electrons per cc, we get the scattering coefficient

$$\sigma = \frac{2\pi ne^4}{m^2c^4}\left\{\frac{1+\alpha}{\alpha^2}\left[\frac{2(1+\alpha)}{1+2\alpha} - \frac{1}{\alpha}\log(1+2\alpha)\right] + \frac{1}{2\alpha}\log(1+2\alpha) - \frac{1+3\alpha}{(1+2\alpha)^2}\right\} \tag{4}$$

The testing of these formulae can be approached either by the measurement of scattering intensity or by the determination of the absorption coefficient. In each method there are special advantages and disadvantages. For example: since the scattered radiations are of different hardness, their effect on the ionization chamber or electroscope are different from that of the primary radiation, or that of radiations scattered at another angle; on the other hand, the measurement of scattered radiations gives the intensity distribution directly. The absorption measurement has the advantage of dealing with greater intensity, but it only tells the net loss, which might include different causes than true scattering. Better information can only be obtained by the carrying out of both methods. The present work deals mainly with the measurement of the absorption coefficient of hard γ − rays, although several scattering measurements have also been made to supplement it. ThC″ is used as the source of γ − rays.

II. **Previous work:** A large number of contributions on the determination of the absorption coefficient of γ − rays can be found in the literature. But different authors usually obtained different results. A good summary was given in Kohlrausch's Handbuch der Experimentalphysik, Vol. 15, Radioaktivität. The main causes of the previous discrepancies are the following:

1. Most determiantions were made on the γ −rays of RaC. Unfortunately, the γ −rays from RaC are very inhomogeneous, as shown in the secondary β −ray spectrum. So it is very difficult to draw any definite conclusions as to the relation between the frequency and the absorption coefficient measured.

2. Errors were often introduced due to the unsuitable experimental arrangement. In most cases the source was not well screened, divergent beams were used, and the absorber was put too close to the measuring apparatus (electroscope or ionization chamber). In consequence an appreciable amount of scattered radiations was received, and this made the result unreliable. In several experiments like those of Kohlrausch the experimental conditions were quite favorable, but the inhomogeneity of the radiation still made it difficult to interpret.

ThC″ is found to give a narrow band of γ − rays of wave−length around 4.7 xu, which is quite intense and far removed from the remaining γ − ray spectrum usually occuring together. Table I shows the composition of the γ − rays of ThC″ obtained by Black[9] and re−computed by Bastings[10].

TABLE I

λ(xu)	K.V.	I(β)	I(γ)
45.1	277	39	2.3
22.5	515	25	9.3
4.7	2649	5.5	88.4

In the above table, K.V. represents the energy of each light quantum in kilovolts, I(β) the intensity distribution on the β −ray spectrum due to different γ − ray components, and I(γ) the intensity distribution of the γ − ray components themselves. The requirement of the