Nagaoka's Geophysical Studies and Their Role in His Physical Researches

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§ 1. Introduction

Hantaro Nagaoka (1865–1950) was one of the outstanding Japanese scientists for the period between the last one decade of the previous century and the first half of this century. He wrote about 350 papers during his scientific activities. Through his life, he had a great interest in geophysical sciences and gave out about 150 papers on these sciences, which were not less than 43% of his whole published papers.

Our research group, whose members are Dr. Kiyonobu Itakura, Dr. Eri Yagi and myself, has completed a biography of his works. (This will be soon published in Japanese.)

In this paper, we discuss the character of his viewpoints of geophysical sciences and the role of his studies on this field in his whole researches.

§ 2. A Summary of Nagaoka's Personal History[1]

H. Nagaoka was born at Ōmura, Nagasaki Prefecture, in the southern part of Japan, as a son of Jisaburo Nagaoka (1839–91) who was a *samurai* in Tokugawa Period and visited Europe and North America as a member of a group for inspection, sent by the Meiji government during 1871–73. H. Nagaoka went to Tokyo for studying the European culture and science by his father's advice at about eight years old.

He graduated from the Colledge of Science of the Imperial University (the present University of Tokyo) in 1887. At the same time, he started to carry out his scientific activities as a graduate student of the University. He obtained a *Rigakuhakushi* (D. Sc.) in 1893. In the same year, he was sent to Germany

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[1] Nagaoka's brief biographies and list of his papers in foreign languages have been published as follows: *Anniversary Volume dedicated to Professor Hantaro Nagaoka by His Freinds and Pupils on the Completions of Twenty Five Years of His Professorship* (1925) i-iv, Tokyo (English).

H. Yukawa: *Nature*, **168** (1951), 409 (English).

Z. Yamauti: *Proies-Verbaux, Comité international des Poids et Mesures* (1951), 200-202 (French).

T. Kimura, K. Itakura and E. Yagi: *List of Hantaro Nagaoka's Papers in European Langauges* (1966), pp. 38 (mimeograph).

as a government student for the study of theoretical physics. At the University of Berlin, he attended the lectures of H. L. F. von Helmholtz, M. E. L. Planck, I. L. Fuchs and H. A. Schwarz, and visited A. A. E. Kundt's labolatory. At the Universities of Munich and of Vienna, he attended the lectures of L. Boltzmann and F. Lindemann. He was deeply impressed by Boltzmann's atomism. After three years' stay in Germany he returned home and was soon appointed Professor (of the theoretical physics) of the Imperial University (of Tokyo). He held this position from 1896 until 1926.

Besides, he was an active member of the Institute of the Physical and Chemical Researches which was founded in 1917. After the retirement from his professorship in 1926, most of his scientific activities were carried out in the Institute.

He was a member of the Earthquake Investigation Committee for 1892–1926, and of the Geodetic Committee for 1899–1927. He was also a member of the Earthquake Research Institute at the Imperial University of Tokyo from the foundation in 1926 up to his death in 1950.

Nagaoka was an active science administrator in Japan, and received various honors.

He was elected a member of the Imperial Academy (the present Japan Academy) in 1905 and took the responsibility of the President of the Academy for 1939–48, and was a member of the House of Peers as the delegate of the Academy from 1934 until the abolition in 1946. He was appointed a member of the National Research Council of Japan (the chairman of the Division of Physics, and later the Vice-President) for 1920–43. During 1931–34, he was the first president of the Osaka Imperial University (the present Osaka University) which was established in 1931. He was also appointed the Head of the Science Division of the Society for the Promotion of Scientific Researches in 1932 and later became the Chief Manager of the Society for 1936–46. During the World War II, he was an advisor to the army and navy in various technical problems.

He was appointed the vice-president of the Union Internationale de Radio Scientifique in 1928, and a member of the International Committee for Weights and Measures in 1931 (until 1948).

He was elected an honorary member of the Société des Physiques et d'Histoires Naturelles of Geneva in 1901, of the Leningrad Academy in 1931, and of the Physical Society of Japan in 1950 and other scientific societies in Japan. He was appointed the Councilor of the Société Française de Physique for 1903–05, and an honorary fellow of the Physical Society of London in 1912. He received the honorary degree of the Doctor of Philosophy from the University of Cambridge, and the Order of Culture Merit, a metal of high distinction of Japan, in 1937.

He had traveled in Europe and North America at eight times as the delegates

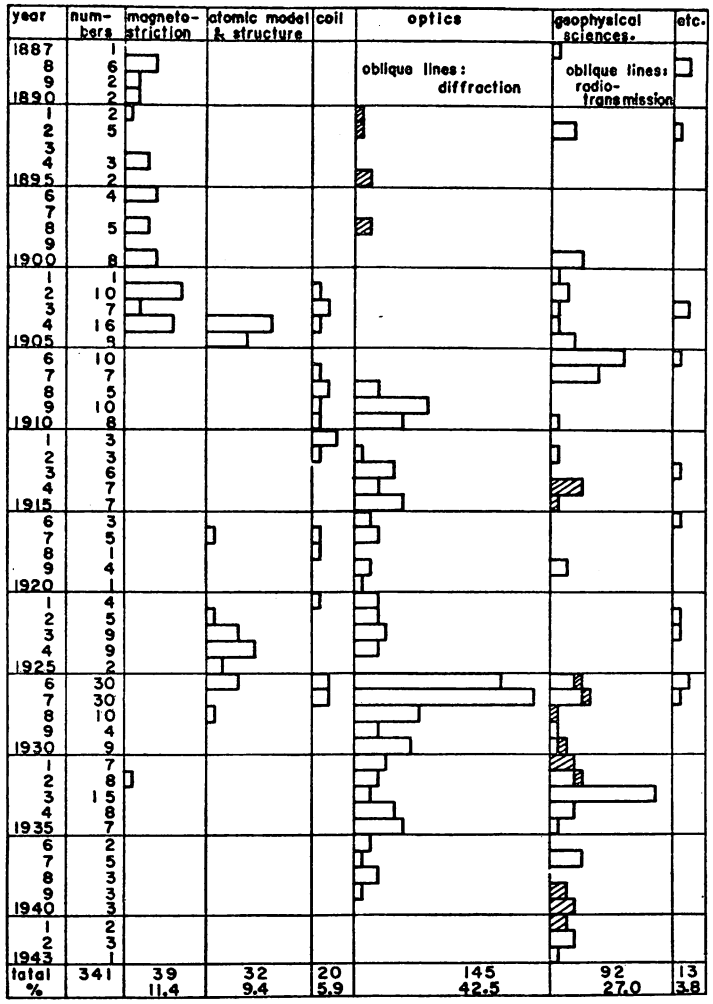

Fig. 1. Classified Nagaoka's papers.

of the Japanese government and scientific societies for attending the international scientific meetings.

He died suddenly at his own study room in Tokyo in 1950.

§ 3. Nagaoka's Physical Researches (except Geophysical Studies)

Nagaoka's scientific activities covered diverse fields of physics and of physical sciences. His earlier works were on magnetism and geophysics. In his studies of the former, he had attempted various kinds of experimental studies of ferromagnetism, especially, of magnetostriction and published thirty-eight papers for seventeen years. Afterwords, these researches were further extended by his

student, Kotaro Honda (1870–1954) who organized a research center of Japan for magnetism in the Tohoku Imperial University (the present Tohoku University) which was established in 1911. Nagaoka attended the first International Congress of Physics held at Paris in 1900 and delivered a paper on magnetostriction by request of the Organization Committee. He said that he was deeply impressed by M. Curie's lecture on radioactivity and J. H. Poincaré's suggestion on the structure of atoms at the Paris Congress.[2]

His earlist theoretical works treated the problems of diffraction of a telescope. He published six papers in this field.

On December 5, 1903, he read a well-known paper on the Saturnean atomic model before the monthly meeting of the Tokyo (later Japan) Physico-Mathematical Society which has been separated into the Physical Society of Japan and the Mathematical Society of Japan. In 1904 and 1905, he published a series of papers in which he discussed line- and band-spectra, radioactivity, dispersion of light and others in relation to his atomic model.

At the same time, he interested in problems of inductance. Subsequently, he published about twenty papers on these problems. Especially, he calculated the socalled "Nagaoka's Coefficients" of the self- and mutual-inductances of coaxial circular coils which are still used in the practical radio-technics. In 1922 and 1926, he published two numerical tables which were tabulated the elliptic functions in relation to these coefficients and themselves.

In 1908, he took up work on the field of spectroscopy. His earlier works in this field were on the Zeeman effect and the fine structure of the spectra of mercury. He continued to study spectroscopy at the Imperial University of Tokyo and the Institute of Physical and Chemical Researches with cooperation of many excellent pupils and followers for about thirty-seven years. Nagaoka published about 140 papers on the field of spectroscopy. He invented several useful methods and devices for his spectroscopic experiments. For example, he improved the method of crossed spectra by the combinations of the different interferometers, especially, Echélon grating and Lummer-Gehrcke plate by which the accuracy of measurement in his spectroscopic works was greatly increased. In his spectroscopic studies, he took up various kinds of substances: Hg, Cd, Bi, Ne and other kinds of gases and metals, radioelements and others. He also studied various kinds of spectra: hyperfine structures, spark lines by disruptive discharge, Zeeman-, Stark- and isotope effects, and others.

After 1921, he wrote about twenty papers on the theoretical discussions of atomic structures and nuclei. In 1924, he announced the success on the transmutation of mercury into gold in his Institute. The report was rapidly spreaded over the world. Since then, he continued to reexamine the transmutation with

[2] E. Yagi: *Jap. Stud. Hist. Sci.*, No. 3 (1964), 29–45; No. 6 (1967), 19–25.

the help of most of all members of his laboratory for several years. Finally the success was denied.

His main purpose of the such experimental and theoretical researches in spectroscopy and transmutation of mercury might be understood as his strong interest to the structure of atoms and nuclei. The researches in nuclear physics in Japan have been further extended by Yoshio Nishina (1890–1951) who was called "the father of the nuclear physics in Japan", two Nobel Prize winners, namely Hideki Yukawa (1907–) and Sin-itiro Tomonaga (1906–), and others.

Nagaoka took out several patents from Japan and the foriegn countries for his devices, invented in his Institute.

He was very interested in the history of sciences. He supervised to study the life and works of Tadataka Inō (1744–1818) who was the great land-surveyor and cartographer in Japan in the Tokugawa Period. Thus, Ryokichi Ōtani (1875–1934) completed a book on Tadataka Inō (in Japanese) published in 1917.[3] Nagaoka wrote a preface to Ōtani's book. When Nagaoka was the President of the Imperial Academy, he promoted the researches and publication of *Meiji-zen Nippon Kagakushi* (history of sciences in Japan before Meiji Period) which became the main work of the Academy. A series of the books (26 volumes) had been published until 1968.[4] He wrote many short biograpies of the famous European physicists and mathematicians in the Japanese popular magazines.

§ 4. Nagaoka's Researches in Geophysical Sciences

Nagaoka's earliest works were the observation of terrestrial magnetism. At the same time of the graduation from the Imperial University, he participated in the Northern Party, one of the two parties, for making a geomagnetic survey of all Japan. He assisted earnestly C. G. Knott (1856–1922), the leader of the party, who was a foreign professor of physics at the University (for 1883–91), and they surveyed the northern part of Japan for three months. Nagaoka also observed the disturbances of isomagnetics caused by the Mino-Owari Earthquake which occurred in the central Japan with many disasters in 1891. He was helped by Aikitu Tanakadate (1856–1952) who was a great scholar on geophysical physics in Japan.

Nagaoka undertook the relative gravity measurement between Tokyo and Potsdam, and the absolute gravity measurements at several places including Tokyo in Japan with his collaborators. According to these field works, the observed values of gravity in Japan could be understood in connection with the European ones. In 1900, he also attended the Thirteenth General Meeting of the International Association of Geodesy held in Paris, as a Japanese delegate, and

[3] R. Otani: *Tadataka Ino, the Japanese Land-Surveyor*, translated in English by K. Sugiura (1932) pp. 358, Iwanami, Tokyo.

[4] S. Yajima: *Jap. Stud. Hist. Sci.*, No. 7 (1968), 159–166 (book reviews).

delivered a paper on the determination of gravity in Japan.

He surpervised the observation of seiches in many lakes and bays in Japan from 1900 by the request of the Earthquake Investigation Committee.

He was regarded as the first physicist to carry out a systematic study on the elasticity of rocks in relation to the propagation of seismic waves through earth's crust. His first paper on the subject was published in 1900.[1] Until 1907, he published twenty-three papers about the speculative discussions of geophysics in relation to seismic and sea waves, and others. His theoretical discussions on geophysics belong to such a shool of the European mathematical physicists as Lord Kelvin, Lord Rayleigh and others. By the means of the mathematical physics, they deduced the various properties and structures of the interior of the earth which could scarcely be taken direct observations. Nagaoka said about the usefulness of the deduction in an introduction of his paper, "Stationary Surface Themor"[5]:

> The problem of elastic surface waves on an isotropic solid was first treated by Lord Rayleigh in 1885. The important bearing of this class of waves on earthquakes was recognised by him, but the result of analysis in its practical aspect has scarely been discussed, inasmuch as the hypothesis of isotropy of the medium is hardly compatible with the structure of the earth's crust. When the great complexity which will be introduced into the boundary conditions (of the actual stratigraphical structure) is taken into account, the advantage gained does not easily compensate for the mathematical difficulty which necessarilly accrues in the solution of the problem. But if the result of calculation based on a simple abstraction as to the nature of the medium be interpreted in the light of a simple comment as to the character of the motion which is capable of being excited on the surface of the elastic solid, the analysis would not to be a useless piece of mathematical play, as the conception of the phenomena is thereby great facilitated.

Nagaoka's studies on this field formed the second peak of a number of his published papers after his retirement from the University of Tokyo. He studied various fields of geophysics covering the physical properties of earth's crust, vibrations of the elastic solid and fluctuations in secular variations of the earth's pole caused by earthquakes and volcanic eruptions, and others. Futhermore, he took up the geomorphological changes and formation of mountains, lines of fissures and continental margins in relation to the isostatic motion in earth's crust with the change of geoid. He reported these studies before the most of every monthly meetings of the Earthquake Research Institute. His viewpoints of discussions in these reports were often criticized by his successors. They

[5] H. Nagaoka: *Publications of the Earthquake Investigation Committee in Foreign Languages*, No. 22B (1906), 17-25.

considered that his reports were too much speculative and proofless from the observation of natural phenomena. From 1926 to 1935, Nagaoka published about thirty papers on that field.

Nagaoka aimed at the improvement of pendulum for gravity measurement. He reported the construction of an invariable tungsten pendulum in 1926 and a silica glass one in 1930, respectively.

He was interested in radio-transmission and ionospheres. In 1914 and 1915, he published four papers on the effects of sunrise, sunset, sunspots and solar eclipse on radio-transmission. His studies on the field had further been extended since 1926 when the Committee of Radio-Physics was organized (he became the Chief), in the National Research Council of Japan. He published ten papers on the discussions of various phenomena of the propagation of radio waves and the effects of solar eclipse and meteoric showers for 1926–32.

He constructed a magnetograph for the measurement of sudden changes on magnetic fields in 1937. He began to study those changes of terrestrial magnetism accompanying volcanic activities and magnetic storms of inospheres by the help of his collaborators. For 1937–43, he published fourteen papers on this subject.

In his last paper in 1943, he discussed the minute fluctuations in the period of rotation of the triaxial earth.

After retiring from the Institute of Physical and Chemical Researches in 1946, he continued to study geophysics at his home until his last time, but no paper was published.

His studies on geophysical sciences were the most fruitful for 1900–07 and for 1926–35 as shown in Fig. 1. In the former period, the theories of oscilation applied in the discussions of his atomic model were also used in his physico-mathematical studies of seismic and sea waves. In the latter period, he took aim at the application of the theories of elasticity and plasiticity to geophysics comprising seismology and geology. Furthermore, he even undertook to build up the electron theory of terrestrial magnetism from the standpoint of ionized atoms and molecules in the interior of the Earth, which was reported by himself to the General Headquater of Allied Forces occupied Japan. A copy of this report is preserved at the National Science Museum with Nagaoka's notes, correspondences, diaries and others.

§ 5. Conclusion

Nagaoka had the continuous interest in geophysics through his scientific activities. His studies on atomic model, and stucture of atoms and nuclei could be regarded as his source researches.[6] He devoted himself to these researches, especially for 1903–05 and 1922–26 as shown in Fig. 1. After these periods,

[6] E. Yagi: *Jap. Stud. Hist. Sci.*, No. 11 (1972), this issue.

many papers on his experimental studies on optics included spectroscopy and others were started to be published successively and his geophysical studies also became much fruitful mentioned above. Therefore, it should be pointed out that his research in geophysical sciences had played a subordinate role for his physical researches, except his earlier works. Torahiko Terada (1878–1935), Professor of the Imperial University of Tokyo, who was a great scholar on physics and geophysics in Japan, was said to point out that Nagaoka's geophysical studies were only a hobby for him.[7] Nagaoka's standpoints of theories of oscillation applied to seismic and sea waves could be common to the one used to his atomic model. His discussions on the base of elasticity and plasiticity of the earth's crust in his later period should be the extension of these geophysical standpoints. The discussions of radio-transmission and ionospheres could be applied the fruits of the experiences of his studies of spectroscopy and atomic structure. For example, he appointed out that states of electric particles in ionospheres were anologous to the one of electrons in a vacuum tube. His geophysical studies could be regarded as his sink researches.

Acknowledgements

The author wishes to thanks Dr. E. Yagi and Dr. K. Itakura for many helpful discussions.

[7] U. Nakaya: Nagaoka and Terada (Japanese), *Nakaya Ukichiro Zuihitsu Sensyu* (Selected Essays of Ukichiro Nakaya) Vol. II (1969), 287–290, Asahi Simbun Press, Tokyo.