

The Compton-Millikan Controversy On the Latitude Effect

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요 약

우주선은 20세기 초에 물리학자들의 관심을 끌면서 등장한 새로운 물리학의 연구 분야였다. 1930년대 초반까지 풀리지 않고 있던 우주선 분야의 주요 문제는 바로 우주선의 본질이 과연 무엇인가 하는 것이었다. 이 문제에 대해서는 단지 두가지 가설만이 존재하고 있었다. 하나는 우주선이 감마선과 같은 광자라는 가설이었고 다른 하나는 우주선이 전자와 같은 대전입자로 구성되어 있다는 주장이었다. 이들 중 광자설이 보다 널리 받아들여지고 있었는데 미국의 밀리칸은 광자설을 가장 강력하게 주장했던 대표적인 인물이었다. 그러나 30년경까지 이 두 주장은 모두 가설에 머물고 있었다.

이러한 상황에서 컴프턴은 우주선연구에 뛰어들어 광자설에 대한 결정적인 반대증거를 찾아내었다. 1932년부터 약 18개월 동안 전세계 물리학자 60여명을 동원해 지구 전역에서 실시한 “대세계 우주선조사”를 통해 컴프턴은 지구자기 위도가 변함에 따라 우주선의 강도가 달라지는 현상을 아주 뚜렷하게 확인하였던 것이다. 오로지 대전입자의 운동만이 자기장의 영향을 받기 때문에 이 위도효과와 발견은 우주선의 본질 문제를 푸는 데 매우 중요한 것이었다. 비록 1927년에 네덜란드의 물리학자 클레이가 위도효과를 처음으로 측정했었지만 그의 측정값은 대부분의 물리학자들에 의해 오차로 치부되었다. 위도효과와 존재에 대한 의심을 제거하고 하전입자설을 타당성을 입증하는 데 일조한 사람은 바로 컴프턴이었다.

그러나 컴프턴의 결과가 과학자들과 대중들 모두에게 인정을 받았음에도 불구하고 밀리칸은 그 결과를 받아들이지 않았다. 밀리칸 역시 이전에 같은 실험을 했었지만 그는 위도효과를 측정하지 못하였다. 밀리칸은 자신의 데이터가 옳고 컴프턴의 것이 틀린 것이라고 생각했고 반대로 컴프턴은 밀리칸의 결과가 아닌 자신의 결과가 옳다고 생각했다. 결국 이 두사람의 노벨상 수상자들 사이에서 위도효과와 존재 여부를 놓고 커다란 논쟁이 벌어지고 말았다. 이 논문은 왜 컴프턴이 그와 같이 위험한 대조사를 시작했으며 밀리칸과의 논쟁은 어떻게 촉발되었고 그 논쟁과 컴프턴의 1933년 이후 연구와의 관련성은 무엇인가를 고찰하고 있다. 컴프턴과 밀리칸은 우주선의 본질에 관해 대립하고 있던 두 이론에 대해 서로 다른 신념을 가지고 자신들의 연구를 시작하였다. 두 사람은 그들이 각자 실험에 사용했던 기구나 그것들의 오차의 원인을 제거하는 데 있어서 가장 중요하다고 생각했던 요소들, 그리고 데이터를 모으고 결과를 분석하는 방법 등에서 완전히 달랐다. 위도효과와 측정을 두고 컴프턴과 밀리칸이 얻어낸 전혀 다른 결과는 바로 이러한 실제적인 차이점들로부터 비롯되었다. 한편 컴프턴은 과학자 사회 내에서 막강한 권력을 행사하고 있고 대중적으로도 자신보다 더 인기있던 밀리칸과 같은 거물급 과학자를 상대로 싸움을 벌이고 있었다는 점에서 심리적으로

불리한 위치에 있었다. 언론 역시 이들의 경쟁관계를 과장 보도함으로써 두 사람의 개인적인 감정을 악화시키는 데 한 몫을 단단히 하였다. 위도효과에 관한 컴프튼과 밀리칸의 논쟁은 바로 이러한 요소들의 복합적인 상호작용의 산물이었다.

In the early 1930s, a big controversy about cosmic rays arose between Robert Andrew Millikan(1868-1953) and Arthur Holly Compton(1892-1962) in the United States and lasted for five years. Unlike most other scientific debates, which are contained within the scientific world, it was announced loudly in public. It can also be distinguished from other scientific controversies in which many scientists participate, in that it was the controversy between only the two scientists. Vicious personal attacks were another characteristic of the Compton-Millikan controversy.

The controversy began with Compton's bold challenge to Millikan's theoretical and experimental investigation into the nature of cosmic rays. The nature of the cosmic-ray had been a great concern to physicists since 1912 when Hess first discovered the rays.¹⁾ Two competing hypotheses about it developed. The photon hypothesis posited that cosmic rays²⁾ are non-electrical particles like gamma rays; the charged particle hypothesis posited that they are high-speed charged particles like electrons. Most European physicists considered the photon hypothesis more plausible despite its lack of experimental evidence. In the United States, Millikan supported the photon hypothesis. The photon hypothesis was an indispensable part of his cosmology, i.e., the atom-building theory. Millikan thought he had justified the photon hypothesis with his experimental results.

During Millikan's development of his cosmology based on the photon theory, an important counter evidence surfaced. It was the 'latitude effect' that a Dutch physicist Jacob Clay first measured near the equator in 1927. The effect, which represents the variation of the cosmic-ray intensity with latitudes, could be expected only under the assumption that cosmic rays are some kind of electrified particles, for only the motion of charged particles is influenced by the geomagnetic field. According to Millikan's theory, which assumed cosmic rays to be neutral photons, the intensity of cosmic rays

1) On the discovery of cosmic rays, see Charles A. Ziegler, "Technology and the Process of Scientific Discovery: The Case of Cosmic Rays", *Technology and Culture* 30 (1989), 939-953 and M. de Maria, M. G. Ianiello, and A. Russo, "The Discovery of Cosmic Rays: Rivalries and Controversies between Europe and the United States", *Historical Studies in the Physical Sciences (HSPS)* 23 (1991), 166-168.

2) It was Millikan who made the term, 'cosmic-ray'. See, M. de Maria and A. Russo, "Cosmic Ray Romancing: The Discovery of the Latitude Effect and the Compton-Millikan Controversy", *HSPS* 19 (1989), 214.

cannot be affected at all by the geomagnetic latitude.

Clay's discovery did not strike a fatal blow to Millikan's conviction of the photon theory, however. Millikan, as well as most other cosmic-ray researchers, failed to measure the variations in intensity larger than the experimental error, and as a result, the photon theory continued to hold a superior position concerning the nature of the cosmic-ray .

Fuzzied by the failure to measure the effect, Compton, along with sixty other physicists from around the world, conducted a 'great cosmic-ray survey' worldwide to check the latitude effect again. Compton got the same results that Clay had obtained, but this time his results were not ignored by scientists. He succeeded in making other scientists and the public believe his results.

There was a hurdle to Compton, however, namely Millikan's strong objection to his results, which he could not but consider seriously. Many physicists in Europe and America in the early and mid 1930s were not much concerned by Millikan's reaction. Actually they ignored his works in their own practice. Compton could not be indifferent to his counterpart's challenge, however. Why did Compton remain in the controversy? How could Compton's 'latitude effect' be accepted, while Clay's was rejected by the scientists? How could Millikan, an experienced and skillful experimenter who had won a Nobel Prize, fail to measure the latitude effect? Is it not strange that such a scientist could not detect the effect which others had already detected? What was the cosmic ray ultimately proved to be? Was Compton the winner? What meaning does this controversy have in the development of the knowledge about cosmic rays? In this paper, I shall examine the controversy with all these questions in mind.

Photons or Charged Particles?

In the late 1920s, the research on cosmic rays entered a new situation with important observations and experiments. Clay's observation of the latitude effect was the first remarkable one that had shed light on the nature of the cosmic-ray. He discovered that the intensity of cosmic rays became lower near the equator.³⁾

Although many scientists had commonly held the view that the cosmic rays are photons, no one could be certain of that. It was merely a hypothesis yet to be proved experimentally. Thus, if Clay's measurement was to be considered credible in this situation, it could prove the charged particle hypothesis. The credibility of Clay's data

3) J. Clay, "Penetrating Radiation", *Royal Academy of Amsterdam Proceedings* 30 (1927), 1115-1127; "Penetrating Radiation II", *ibid.* 31 (1928), 1091-1097; "Ultra Radiation (Penetrating Radiation) III. Annual Variation and Variation with the Geographical Latitude", *ibid.* 33 (1930), 711-718.

was the focus of the matter.

The evidence in favor of the charged particle hypothesis was further enhanced by another — more important in some sense — work : the double 'counter coincidence experiment' by Bothe and Kolhörster in Germany in 1929.⁴⁾

Bothe and Kolhörster arranged two Geiger-Müller counters vertically and inserted lead between the two counters. When individual cosmic ray particles passed through the counters and discharged them, the electroscope connected to each counter measured the ionization rate. Bothe and Kolhörster found that the two counters were discharged almost at the same time in spite of the presence of the absorber between them. This coincidence led them to conclude that the cosmic ray causing the ionization must be a charged particle with an energy sufficient to penetrate the two counters and the absorber with no time delay. If the ionization had been caused by the secondary electron recoiled by a photon when the photon had collided with an atom on the surface of the counter, the energy of the electron would have been too weak to discharge the counters with such rapidity. The Bothe-Kolhörster experiment not only produced a strong support for the charged particle hypothesis, but provided physicists with a motive to solve the problem of the nature of cosmic rays through systematic experiments.⁵⁾

The photon hypothesis was also reformulated by experimental results. In his 1928 papers,⁶⁾ Millikan, who led the cosmic-ray research in the United States in the early 1920s, reported the measurements of absorption coefficients in California lakes. On the basis of the results, he concluded that the photon theory was right. According to the atom-building theory (which had been very important to Millikan since then), at the very beginning of the universe there existed electrons and protons in the form of hydrogen gas. As they were condensed in the cold interstellar space, new elements came into being step by step from the lightest helium to such heavier ones as nitrogen and oxygen. The cosmic ray is the light radiation produced from the never-ending formation process of these atoms. Millikan named it the 'birth cry' of atoms.

From his birth cry theory, Millikan calculated the absorption coefficients of the emanated gamma rays. The theoretical values were 0.35 for helium, 0.08 for oxygen and nitrogen, 0.04 for silicon. The experimental values he obtained in the lakes in California were 0.30, 0.08, and 0.041 for the same atoms. Even the value 0.019 for

4) For the detail of their experiment, see de Maria and Russo, "Cosmic Ray Romancing", 218-220, and Peter Galison, *How Experiments End* (Chicago : Univ. of Chicago Pr., 1987), pp.94-95.

5) Bruno Rossi, *Cosmic Rays* (McGraw-Hill, 1964), p.42.

6) R. A. Millikan, "Evidence for the Continuous Creation of the Common Elements out of Positive and Negative Electrons" (with G. H. Cameron), *Physics* 14 (1928), 445-450 ; "Evidence that Cosmic Rays Originate in Interstellar Space", *ibid.* 637-641.

iron was not inconsistent with the calculated one.⁷⁾ Millikan thought that this band spectrum of cosmic-ray energy was clear experimental evidence for the photon hypothesis as well as the atom-building theory.

Millikan was discouraged neither by the latitude effect nor by the coincidence experiment. Soon after Clay, he also investigated into the latitude effect, but measured no significant variation in intensity with latitudes. He regarded the minor variations he obtained as an error.⁸⁾ In addition, many other cosmic-ray researchers, including even Bothe and Kolhörster, failed to detect a distinct value of the intensity difference larger than the experimental error.⁹⁾ Although Millikan did not yet have a satisfactory explanation of the Bothe-Kolhörster experiment, the failure to detect the latitude effect made him stick to the photon theory.

In 1930, an Italian physicist Bruno Rossi, who had been greatly concerned with the implication of the Bothe-Kolhörster's double counter experiment, obtained more crucial evidence for the charged particle theory. Suspecting that the Bothe-Kolhörster experiment was not completely free from a chance coincidence, he arranged three Geiger-Müller counters with lead bricks between them, and the vacuum tube coincidence circuit to get rid of any unwanted 'accidental' coincidences. He used a mechanical recording device that worked only when all three counters were discharged simultaneously. The result was a simultaneous discharge of the three counters again.¹⁰⁾ Rossi concluded that

.....In fact, they had to possess energies in the range of billions of electron volts. These energies were greater than any that could possibly be released in the synthesis of elements. And for many physicists it was a great disappointment when, in the face of the experimental evidence, *they were forced to abandon Millikan's fascinating theory* about the origin of cosmic rays. Moreover, *the g-ray hypothesis, already shaken by the work of Bothe and Kolhörster, had received an even more serious blow.*¹¹⁾
(Italics are mine)

There was other evidence, more exciting to Rossi: the 'east-west effect', an

7) Millikan, "Evidence for the Continuous Creation" *Physics* 14 (1928), 448-449; "New Precision in Cosmic Ray Measurements: Yielding Extension of Spectrum and Indications of Bands" (with G. H. Cameron), *The Physical Review* (*Phys. Rev.*) 31 (1928), 921-930.

8) Millikan, "High Altitudes Test on the Geographical, Directional, and Spectral Distribution of Cosmic Rays" (with G. H. Cameron), *Phys. Rev.* 31 (1928), 163-173; "On the Question of the Constancy of the Cosmic Radiation and the Relation of These Rays to Meteorology", *Phys. Rev.* 36 (1930), 1595-1603.

9) A. H. Compton, "A Geographic Study of Cosmic Rays", *Phys. Rev.* 43 (1933), 387-388.

10) See, for the detail, Rossi, *Cosmic Rays* (note 5), pp.43-49.

11) *ibid.*, pp.45-46.

asymmetry in the intensity of cosmic rays of the east and the west regions of the earth. Such an asymmetry could be expected to appear when cosmic rays were the particles predominantly of one sign. By detecting the east-west effect, Rossi found that the incoming cosmic rays were mostly positive.¹²⁾ It was now taken for granted that Millikan's position was weakened by Rossi's works. If they put aside the latitude effect, the situation seemed favorable for the charged particle hypothesis. Only the latitude effect was the problem.

At the International Congress on Nuclear Physics held in Rome in 1931, the photon theory was severely attacked. Rossi openly criticized Millikan's photon hypothesis and atom-building theory, basing his attacks on a series of recent experimental evidence. Compton was there, and he was strongly impressed by Rossi's attack on Millikan's theory. Although Compton still did not directly object to Millikan's theory, he was now sure that photon theory is wrong. Returning from the long and profound discussion with Rossi on the progress of the cosmic-ray research till then and on their implications, Compton began to plan the world survey on the cosmic ray.¹³⁾ When he started the survey, he was fully converted to the charged particle hypothesis.

Controversy over Whose Results Are More Credible

Compton thought that detecting the latitude effect was the most urgent thing to show that cosmic rays are not photons.

In view of the strong indication from the Bothe-Kolhörster double counter experiment that *the cosmic rays are high-speed electrical particles*, this *failure* to find a variation of cosmic-ray intensity with latitude was unusual interests.¹⁴⁾ (Italics are mine)

Compton had been largely convinced of the charged particle hypothesis by the Bothe-Kolhörster experiment. Compton used the word 'failure', referring to the fact that most observers had concluded the intensity to be constant and equal within the errors of experiment. If someone "failed" to do something, it must have been because the person made a mistake or was clumsy. What mistake could the experimenter make in detecting the latitude effect? In what respect could he be clumsy? In the various processes of instrument design, the operation of the instrument, measurement, data analysis, and so forth, some causes of the sources of error might have occurred.

12) *ibid* , pp.10, 68-74. Galison, *How Experiments End*, pp.111-112.

13) On the influence of the Rome Congress on Compton, see de Maria and Russo, "Cosmic Ray Romancing, " p.219, and Rossi, *Cosmic Rays*, pp.68-70.

14) Compton, "A Geographic Study", *Phys. Rev.* 43 (1933), p.388.

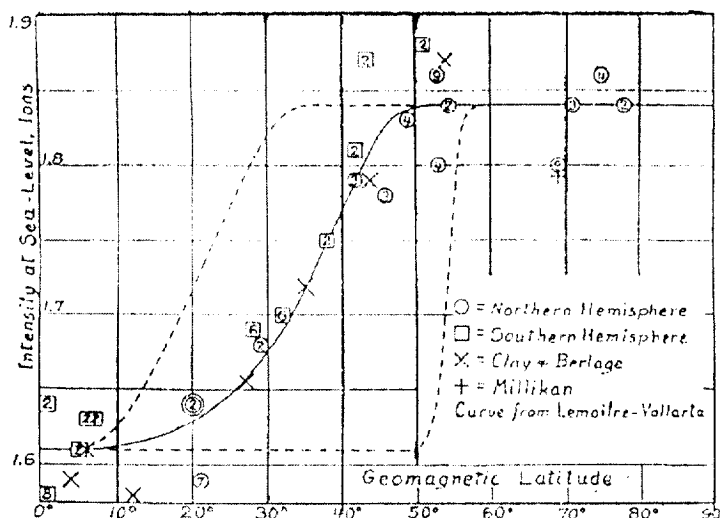


Figure 1. Compton's graph on the cosmic-ray intensity vs. geomagnetic latitude at sea level. The curve was from Lemaître-Vallarta theory. Here Compton placed the three series of results, Millikan's, Clay's, and those of his own, adjacently to one another.

Compton expected that, by removing these sources of error, he could make a 'success' in measuring the latitude effect.

The theoretical basis of Compton's optimistic expectation was the 'explosion theory' of Lemaître and Vallarta. The theory argued that some thousands of millions of years ago there was a primeval explosion of the universe; cosmic rays are the remains of that explosion, which are the mixture of atoms, electrons, even photons, etc. In addition, Lemaître and Vallarta's theory calculated the possible energies of the rays and the degree of affection by the earth's magnetic field.¹⁵⁾ This theory played an important role in convincing Compton that Millikan was wrong and prompted his decision to ask for aid for the world survey on the latitude effect.¹⁶⁾

Compton started the world survey with the financial aid from Carnegie Institute in December 1931, and had nine expeditions up to 1933. As he expected, Compton obtained the results that were in accord with the intensity variation curve predicted by the Lemaître-Vallarta theory. In order to show that his results were right, Compton compared his affirmative results with Millikan's negative one on the same diagram (See, Fig. 1).¹⁷⁾

15) Compton, "Nature of Cosmic Rays", *Nature* 131 (1933), p.713.

16) See Robert H. Kargon, *The Rise of Robert Millikan: Portrait of a Life in American Science* (Ithaca and London: Cornell Univ. Pr., 1982), p.154, and note 19 on p.194.

17) Compton, "A Geographical Study", *Phys. Rev.* 43 (1933), 399.

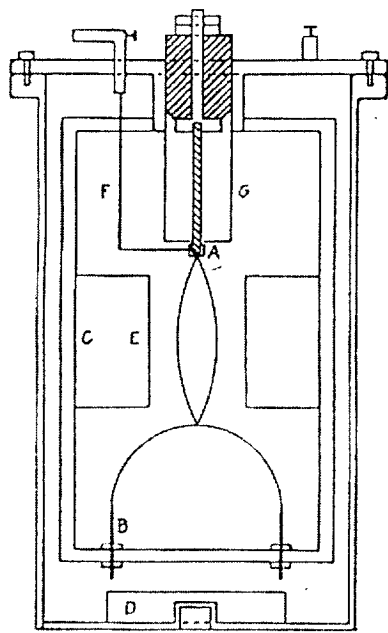


Figure 2. Diagram of Millikan's electro scope, the 1926 type. This was changed into the spherical form in 1928 with the change of some parts inside, but the original mechanism of it was not changed.

As soon as Compton announced the results of the world survey, Millikan checked the latitude effect again in Pasadena and Churchill around 34° N. His results were the same : He measured no variation of intensity which was outside the experimental error of 6%.¹⁸⁾ Millikan never thought of his work as a "failure", however. Instead, for Millikan, Compton's work was a 'failure'. Millikan was confident of his results as much as, or more than, Compton was of his. The controversy over the credibility of Millikan's and Compton's results, of which the judges were the scientists other than the two men involved, was now unavoidable.

How did they obtain such different results? Both Millikan and Compton measured the number of ions per unit volume per unit time (ions/cc/sec) produced in the ionization chamber through which the incoming rays passed. What was different was the way they measured the rate of ionization.

Fig. 2 is a diagram of the electro-scope that Millikan used to measure the rate. Two thin and long quartz fibers, sputtered with platinum to make them conducting, are at the top soldered into a small copper tube G held by a brass cap A, and at the lower ends fastened to a bow of unsputtered quartz fiber.¹⁹⁾ To measure the penetrating radiation, Millikan charged the electro-scope in advance to a known potential with the electrical connection through the charging rod F (See Figure 3).²⁰⁾

18) Millikan, "New Techniques in the Cosmic-Ray Field and Some of the Results Obtained with Them", *Phys. Rev.* 43 (1933), 665-667.

19) Millikan, "High Frequency Rays of Cosmic Origin II: Mountain Peak and Airplane Observations", *Phys. Rev.* 27 (1926), 647-650.

20) Millikan, "Evidence that.....", *Physics* 14 (1928), p. 650.

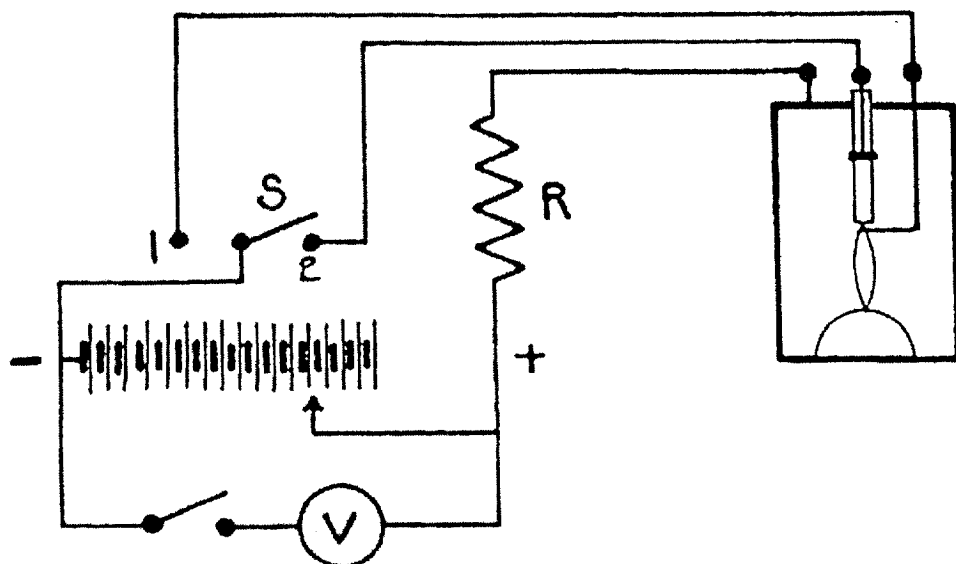


Figure 3. The electrical connection for charging the quartz fibers in Millikan's electroscope.

When the switch S touches 2, the battery potential is supplied with the fibers through F . Then the quartz fibers at the center become wide as shown in Fig. 2. As the penetrating particles discharge the air in the chamber — here, the direct agent of the ionization was the recoiled electrons by photons, not the photon itself — and as the original potential drops, the width of the fibers becomes narrower. The amount of charge leaked out of the fibers, which is observed as the degree of deflection of the fibers, corresponds to the intensity of the incoming cosmic rays into the chamber. Millikan measured the 'fiber deflection' with a microscope and converted the length to the voltage, and then to the ionization current, through a simple calculation.

Compton's instrument was a product of his desire to have an instrument superior to Millikan's.²¹⁾ It consisted mainly of an ionization chamber and an electrometer system (See Fig. 4-a). The ionization chamber, in turn, consisted of a spherical steel bomb which contained an electrode of ionization chamber and a piece of steel rod electrode

21) Compton's great and prudent concern with the instrument is well shown by the fact that he wrote the two other papers devoted fully to the instrument. In them, he worked hard to demonstrate the outstanding and unique characteristics of his instrument when compared with other ones. See Compton, "An Improved Cosmic-Ray Meter", *Review of Scientific Instruments* (*Rev. Sci. Instr.*) 4 (1933), 491-495, "A Precision Recording Cosmic-Ray Meter" (with J. J. Hopfield), *ibid.* 5 (1934), 415-422.

four points through which he drew a straight line on a graph. He used it to find the right potential value corresponding to some position of fibers.²³⁾ Millikan repeated the same procedure to get several such straight lines. Nevertheless, there was a possibility of considerable error in his procedure. For it is almost impossible to detect some minute change in position with a human eye. For example, it is very difficult to detect the fiber deflection corresponding to the potential drop of a fraction of tens or that of a fraction of hundreds. In addition, although Millikan said that "The four points *almost always lay quite close to the line* and it was never possible to make any large error."²⁴⁾ (Italics are mine), drawing a straight line with just four points could be another source of error.

What Compton intended with his electrometer was to reduce such errors. If the sensitivity is high enough, the meter would better detect the small values that are to be measured. Thus, Compton had a complicated outside electric circuit system in his ionization chamber so that the scale of an electrometer may represent the voltage directly (See Fig. 4-b).²⁵⁾ Compton's great concern with accurate instruments dated from the days of his early X-ray research. In his final year of the study for a Ph.D degree at Princeton, he built a new electrometer for his brother Karl, who had researched the passage of electrons through gases. To study such questions as the collision of electrons with gas molecules and ionization and excitation of atoms by it, the electrometer of higher sensitivity than that in common use was needed. Compton found the association between the sensitivity and the asymmetry of the needle and quadrants, and succeeded in building the electrometer that was the most sensitive for many years to come.²⁶⁾ At the University of Minnesota, where he taught physics for a year after receiving his Ph.D., Compton developed a balanced double crystal X-ray spectrometer. Through some experiments with the spectrometer, he could demonstrate that the ferromagnetism in a magnetite crystal is not due to the effect of electron orbital motions of the crystal.²⁷⁾ He also had the experience of developing aircraft instruments for the Signal Corps during World War I; afterwards, he worked at the Westinghouse Electric Company, where he made basic contributions to the development of the sodium vapor lamp which was the predecessor of the fluorescent lamp of the 1930s.²⁸⁾

23) Millikan, "High Frequency Rays of Cosmic Origin", *Phys. Rev.* 27 (1926), p. 649.

24) Millikan, *ibid.*

25) Compton, "An Improved Cosmic-Ray Meter", *Rev. Sci. Instr.* 4 (1933), p. 492.

26) See Compton, "Personal Reminiscences", Marjorie Johnston ed., *The Cosmos of Arthur Holly Compton* (New York: Alfred A. Knopf, 1967), pp. 19-20.

27) Robert S. Shankland, "Introduction" in *Scientific Papers of Arthur Holly Compton: X-ray and Other Studies* (Chicago, London: Univ. of Chicago Pr., 1973), xv-xvi.

28) Shankland, "Introduction", *ibid.*, xvi.

It would seem natural that scientists are familiar with instruments like meters and use them to measure physical quantities. But it was not at all natural for Millikan to use the instrument like an electrometer. For him, what was more natural and credible was to use the experimenter's eye. He thought that auxiliary instruments could be the sources of error, whereas Compton thought that sufficient sensitivity of the instrument could reduce the error.

Millikan had his own idea of reducing the error from his electroscope. He thought that the largest and most serious error could be produced from the leak of the charges in the fibers toward G (Fig. 1). To prevent the charge-loss out of the chamber toward G, he set the 'guard ring' connection that kept the G part and the fibers at the same potential (See the '1' in Fig. 3).²⁹⁾ This idea was excellent in principle. If it had been realized completely, there would have been no large error as Millikan hoped. But it must have been very difficult to keep the two positions at the same potential each time. Whenever the fiber deflection occurred, Millikan had to regulate the potential at G with the values of the points on the potential-deflection line, which must have caused error as I mentioned above.

The length of the time of the deflection of the fibers may have caused a problem also. It was common to use 'hour' as a unit of time in measurements of the cosmic-ray intensity. It means that the measured ionization rate was so small that they needed quite a long time to figure it out. But an hour is such a large unit of time that there can be some loss of charge for that period. There could also be a spontaneous leak of charges from the case to the outside, even if it was insulated. Millikan, who did not think of them as the main sources of error, took no action to prevent the losses. He just thought that the most important source of error was the loss of the charges in the fibers and the change of position of the quartz fibers, for the fiber deflection was the primary quantity to be measured. The loss of the charges in the case was a minor problem to him. Allowing sufficient tension to a bow attached to the fibers at their lower ends, he kept the quartz fibers from moving with pressure or temperature; it was all he did to prevent the loss.

What Compton sought was to remove or minimize these sources of error, which Millikan considered "trivial". For Compton, the small difference of measured values was very significant, as can be seen in the following remarks.

Millikan's measurements were made at latitudes varying from 34°N to 59°N, most

29) Millikan, "High Frequency Rays of Cosmic Origin", *Phys. Rev.* 27 (1926), 650-651.

of them being at about 40° N. Our measurements near this latitude are in satisfactory agreement with his considering the slight differences in experimental arrangement. We do not however confirm the independence of the intensity of latitude which he reports.³⁰⁾

The two scientists were different in their interpretation of the slight difference in measured value: One considered it as a mere error, the other took it to be significant. Compton made every effort to eliminate all sources of error, whether large or small, to prove his argument.

The most important cause of error, Compton thought, was various kinds of leakages. Since the value which the electrometer needle indicated was the rate of charging, any leaks, such as the inflow of the air into the bomb, the outflow of the gas in the bomb, and the electric leakage between the bomb and the needle, could change the potential directly. Using rubber gaskets, amber, driers, and a mixture of beewax and resin etc., Compton thoroughly insulated every part and connection of the whole instrument including the electric circuit system.³¹⁾ He also shielded the local radiations other than cosmic rays with triple layered spherical shells of bronze and lead as in Fig. 4-a and made the correction of the effect by local rays by means of mathematical calculation.³²⁾

Compton took pains not only to minimize all possible errors but to improve the accuracy of data. To fill argon in the chamber was the first step to improve the sensitivity of his instrument. It was air, not argon, that had been commonly used till then. Before the world survey, Compton found that the degree of ionization of argon was much higher than that of air or nitrogen under the same pressure and that the gap in the ionization rate was getting larger as the pressure became high.³³⁾ With argon, it was possible to detect even extremely weak ionization current. To expand the region and the scale of the expeditions was the second step to increase the number of the positive data. The expeditions, in which over sixty physicists — eighty by 1934 — around the world participated,³⁴⁾ covered the earth from 47° N to 46° S.

30) Compton, "Variation of Cosmic Rays with Latitude", *Phys. Rev.* 41 (1932), p. 113.

31) Find the detail on the means and method for leakage-proof in Compton's papers: "A Geographic Study of Cosmic Rays", *Phys. Rev.* 43 (1933), 392, "An Improved Cosmic-Ray Meter", *Rev. Sci. Instr.* 4 (1933), 492-493.

32) Compton, "A Geographic Study", *Phys. Rev.* 43 (1933), 390-393.

33) Compton, "Use of Argon in the Ionization Method of Measuring Cosmic Rays" (with J. J. Hopfield), *Phys. Rev.* 41 (1932), 539.

34) Compton, "Recent Developments in Cosmic Rays", *Rev. Sci. Instr.* 7 (1936), 72.

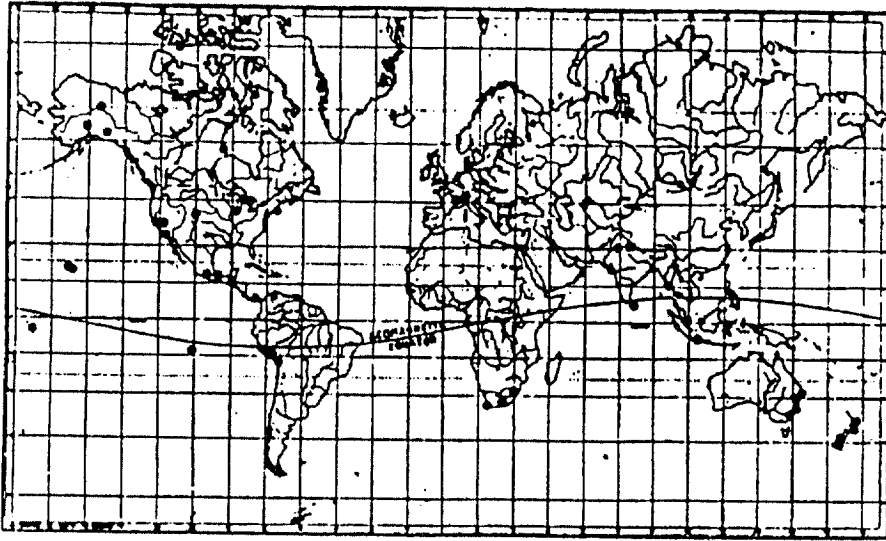


Figure 5. Compton's world survey map during 1932.

except east Asia and Russia (See Fig. 5)³⁵⁾. To get as much data as possible was the third step.³⁶⁾

The difference in the two scientists' views about the more credible method for successful measurement and about the more effective explanatory strategy for obtaining necessary support was as big as the generation gap of more than twenty years between them. The difference was reflected in the way that they explained what they did as well as how they designed and operated their instruments. Millikan's explanation of his practices was quite narrative and his analysis of the results was qualitative, compared with those of Compton's which were analytic, mathematical, and quantitative.

The controversy was mainly over the question of whose results were more credible, but at the same time it was about whose methodology was more appealing. Also important was the question of who judged their results. For us today, Compton's results seem more credible and his explanation seems more persuasive. But the actual judges in this case were the physicists in the 1930's in Europe and the United States.

Of course they also accepted Compton's results, which were the same as what Clay had obtained.³⁷⁾ It means that Compton's experimentation and explanation appealed to

35) Compton, "Nature of Cosmic Rays", *Nature* 131 (1933), 713.

36) Compare the table III in p.242 of Millikan's "A More Accurate and More Extended Cosmic-Ray Ionization-Depth Curve and the Present Evidence for Atom-Building" (with G. H. Cameron) in *Phys. Rev.* 37 (1931) with the table III on p.394 of Compton's "A Geographic Study" in *Phys. Rev.* 43 (1933).

37) See de Maria and Russo's remarks on p.249 of their article, "Cosmic Ray Romancing", *HSPS*

them more than those of Millikan's and Clay's. It shows that the judges in the 1930's were familiar with Compton's more technical instrumentation and analytic, quantitative methodology as much as Compton himself. Those of Compton's generation must have been more concerned with modern technology and had more experience and knowledge about it than those of Millikan's generation. If Millikan's results were thought less scientific compared with Compton's, it must have been because the judges had viewed Millikan's strategy of demonstration as less scientific or less sophisticated.

No Winner, No Loser, and No Observer

We cannot say that Compton won the controversy. Although it was true that the results of the world survey were accepted, it did not mean that Compton was the winner and Millikan was the loser of the controversy on the nature of cosmic rays. It only meant that no one except Millikan and a few colleagues of his came to negate the latitude effect. As a matter of fact, the real important problem over which the two scientists were fighting was not that of the latitude effect, but that of whether the cosmic rays are photons or mostly charged particles. They would not give up their opposite opinions on that.

Who was right in predicting the nature of the cosmic ray? Both were right and both were wrong. The latitude effect was a necessary but not sufficient evidence to prove that all the cosmic ray particles are charged. True, Compton did not argue that all the cosmic rays are charged particles, but he still said almost all of them are charged particles. He took the Lemaitre-Vallarta theory not only as the theoretical basis for his observational data but also as the tool for justifying the charged particle hypothesis, while actually Lemaitre and Vallarta emphasized that the cosmic rays were mixtures which include electrons, protons, photons, or other unknown types of particles. Their point was that cosmic rays contained charged particles also.³⁸⁾ Combining such theoretical consideration with his survey results, Compton drew a conclusion that only

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38) In their paper "On Compton's Latitude Effect of Cosmic Radiation", Lemaitre and Vallarta say that "This discovery (of Compton and Clay) *rules out the hypothesis that the cosmic radiation consists of photons alone* and suggests that it is made up at least partly of electrons, protons or other charged particles." (*Phys. Rev.* 43 (1933), 87) and that "From the examination of the curves... It seems possible to represent the experimental curve by a suitable mixture of rays of these energies, but *it is not at all excluded that a part of the radiation may consist of photons or neutrons*..... In presenting this theory one of the present authors wrote: "I think that a possible test of the theory is that, if I'm right, *cosmic rays cannot be formed uniquely of photons, but must contain, like the radioactive rays, fast beta-rays and alpha-particles, and even new rays of greater masses and charges.* I have shown that the momenta of such rays must be reduced by the expansion (of the universe) in about the same ratio as that of photons." (Italics are mine) (*ibid.*, p.91).

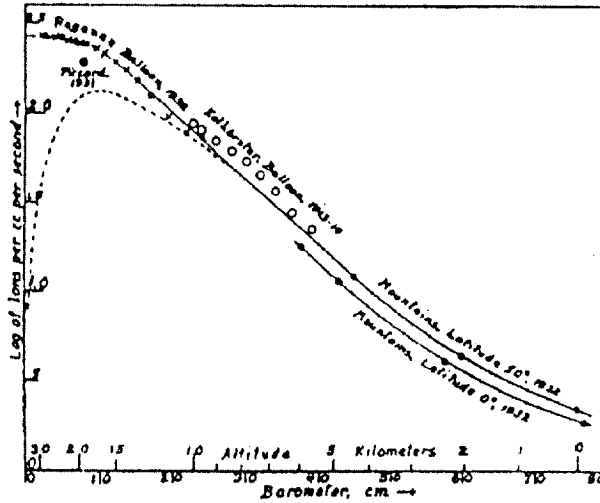


Figure 6. Curve from Piccard and Regener's experiment at high altitudes

very small parts of cosmic rays are composed of photons.

.....Such details have no doubt but that the latitude effect is due to the action of the earth's magnetic field. The existence of the effect accordingly implies that *at least a considerable portion of the primary cosmic rays is electrically charged.*³⁹⁾ (Italics are mine)

Other types of measurements, such as those of Piccard and Regener in their high-altitude balloon flights and Bothe and Kolhörster's counter experiments, lead to the conclusion that *very little of these rays is in the form of photons, like light,*.....⁴⁰⁾ (Italics are mine)

It was true that Piccard's and Regener's experiment clearly showed that unlike Millikan's theoretical prediction, there was no maximum position of the cosmic-ray intensity below the top of the atmosphere. But, as shown in Fig. 6,⁴¹⁾ the cosmic-ray intensity curve with altitude had not increased absolutely but approached some limit. The limit came from the effect of photons, albeit a small quantity. What Compton emphasized was the smallness of the quantity of photons rather than the limit approached by the curve due to the influence of photons. I do not mean that Compton was ignorant of, or neglected, the implication of the Lemaitre-Vallarta theory. On the

39) Compton, "Recent Developments in Cosmic Rays", *Rev. Sci. Instr.* 7 (1936), p.73.

40) Johnston ed., *The Cosmos of Arthur Holly Compton*, p.162.

41) Compton, "Nature of Cosmic Rays", *Nature* 131 (1933), p.715.

contrary, he knew it well, and seemed to exaggerate it rather intentionally so as to oppose Millikan. In fact, most other physicists working actively in the early 1930s had no scientific interest in the controversy between Compton and Millikan. They were interested in the cosmic ray itself, which could play a key role for testing the theories of quantum electrodynamics (QED). Their greatest concern was the phenomena, called 'cosmic-ray showers', the burst of particles that had been observed on the surface of the metal plate like lead in a cloud chamber or a counter, when an individual cosmic ray passed through it. These shower particles were neither the ordinary electrons nor protons. To be electrons, their values of energy loss calculated by the QED were much larger than the experimental values; to be protons, the energy distribution of the rays from experiments could not be smoothly explained. It provoked the fundamental question of whether the QED was right, and led the physicists to ponder over the existence of the new particles which are neither electrons nor protons. Theoretical and experimental research for identifying the new particle had been the top subject for most renowned physicists until the late 1930s.⁴²⁾

Their attitudes toward Millikan were indifference on the one hand and avoidance on the other. From the beginning, there were few scientists who thought the atom-building theory physically plausible. Rossi said that it was romantic rather than scientific,⁴³⁾ Rutherford, Chadwick, and Oppenheimer pointed out the risk of Millikan's attempt to calculate the absorption coefficients of the penetrating radiation directly from the Klein-Nishina formula.⁴⁴⁾ It was even said that his theory was violating the second law of thermodynamics in that it was arguing over the endless cycle of creation of matter.⁴⁵⁾ Compton's latitude effect, Rossi's triple-counter experiment and the east-west effect, and Piccard's and Regener's experiment, all seemed to make it clear that Millikan's 'photon-all theory' was wrong. Nevertheless, as the physicists knew well that Millikan's belief of the atom-building theory was so firm that he would never give up or modify it, they did not want to interfere with him. Thus, while the physicists in Europe, working at a long distance from Millikan, were naturally

42) See Galison, *How Experiments End*, pp.96-131 for the theoretical crisis of quantum electrodynamics and the discovery of the new particles. David Cassidy's "Cosmic Ray Showers, High Energy Physics, and Quantum Field Theories: Programmatic Interactions in the 1930s, *HSPS* 12 (1981), 1-39 is another reference for the popular research topic to physicists in those days.

43) See Rossi, "Arcetri, 1928-1932", in Yataro Sekido and Harry Elliot eds., *Early History of Cosmic Ray Studies* (Dordrecht: Reidel, 1985), pp.53-54.

44) Ernest Rutherford, *Proceedings of the Royal Society of London* 122A (1929), 15; J. Chadwick, *ibid.* 132 (1932), 343—recitation of note 88 on p.192 of Kargon's *The Rise of Robert Millikan: The Oppenheimer's letter to Millikan, February the 12th in 1929—recitation of note 85 on p.85 in Galison's How Experiments End.*

45) de Maria and Russo, "Cosmic Ray Romancing", 214-218.

indifferent to his theory, those in the United States evaded the exhaustive debate with him, since he would not be discouraged by anything or by anyone.

No one in the American scientific society in those days would go out of his way to irritate Millikan after all. He was the most famous and the most popular scientist in the United States through 1920s. As the second Nobel prize winner of a scientifically underdeveloped country, he represented American science publicly; as a man of career ambition, he was the leader of the scientific community.⁴⁶⁾ In 1922, he moved from the University of Chicago to the California Institute of Technology, where he launched his cosmic-ray research program. As a full-time director of Caltech, which had been the Mecca of the American science and the symbol of the political power through the twenties, Millikan had held the unique position to exercise a strong influence over the scientific community.⁴⁷⁾

Although the scandal involving the oil-drop experiment⁴⁸⁾ and the controversy with Compton corroded his fame to some degrees, Millikan was still an influential figure in the early 1930s, particularly in launching and directing a scientific program or policy. It was C. D. Anderson, the most talented disciple of Millikan, who had done some experiments with a cloud chamber, one of the main instruments for studying the shower particles, to discover the positron in 1933.⁴⁹⁾ The discovery of positron started new experimental research in physics and, even though Millikan himself interpreted it as another evidence for the photon theory, the positron could not have been discovered but for his command or permission to do the experiments.⁵⁰⁾ Anderson and the cloud chamber played a decisive role in the further experimental study of nuclear physics from then until the late thirties.⁵¹⁾ Ultimately the continuous experiments with a cloud chamber made Anderson, who had first agreed with Millikan, turn away from the latter's theoretical position after 1934.⁵²⁾ Considering the situation, it is not

46) To know the popular fame and the influence that Millikan was having and exercising, his ambition in career, and the endowed ability in politics for success, see Kargon, *The Rise of Robert Millikan*, chap. 1, "A Brief Introduction" and chap. 2, "The Making of a Scientist."

47) See Kargon, *ibid.*, chap. 4, 5 and "Temple To Science: Cooperative Research and the Birth of the California Institute of Technology", *HSPS* 8 (1977), 3-32, Roger L. Geiger, *To Advance Knowledge: The Growth of American Research Universities, 1900-1940* (Oxford Univ. Pr., 1986), pp. 183-189. In these writings, the authors described in detail the role and position of Caltech and those of Millikan in the 1920s in the United States.

48) See Kargon, *The Rise of Robert Millikan*, pp. 151-153.

49) C. D. Anderson, "Cosmic-Ray Positive and Negative Electrons", *Phys. Rev.* 44 (1933), 406-416.

50) Millikan explained that positron is a nuclear particle which comes out of the nucleus when the photon hit it. See Galison, *How Experiments End*, pp. 89-90.

51) See Galison, *ibid.*, pp. 110-133.

52) See Galison, *ibid.*, p. 114.

surprising that none would irritate such an obsolete big gun as Millikan for such a problem as that of the nature of the cosmic-ray, which was not important any more and was recognized to be uncontroversial at least among the scientists. Besides, Millikan was not completely wrong, either. It was true after all that photons were some parts of cosmic rays.

Compton was the only person who neither was indifferent to Millikan's theory nor shielded away the annoying confrontation with him. He might not have been able to do so, had he attacked a set of detailed data with another set in a scientific journal. He aimed straight at Millikan and his work. He compared everything related to Millikan's work and results with his own ones, and openly stated the superiority and reliability of his. Needless to say, it made Millikan nervous and furious.

To Millikan, Compton was the invader into the field that he had pioneered with his own effort. Furthermore, the young scientist dared to challenge his accomplishment publicly and in detail. Predictably, Millikan delivered a severe counterattack against Compton. As for Compton, who came to be involved in the controversy with a man like Millikan, he probably could not but bear the burden of managing and concluding the controversy. At the end the controversy grew into an ugly personal fight. They did not hesitate to launch personal attacks on each other in official ceremonies and in print.⁵³⁾

The press could not be free from the blame for making the controversy hotter and their personal relationship worse. Various newspapers and radio programs made a fuss reporting the event. They exaggerated the conflict of the two top scientists and tried to make a common story dramatic. For the newspaper reporters in particular, who must have been starving for sensational news, it served as a great item. Describing Compton's publication of the world survey results as a serious challenge to Millikan, and attributing Millikan's reaction against Compton to his obstinate adherence to the photon theory, they drove the two scientists to the state of extreme antagonism against each other.⁵⁴⁾ The two scientists could not have kept cool in such a situation.

But did Compton have no choice but to prolong the controversy? Did he have to waste his time and energy on a subject from which all other physicists around him, even Anderson, had turned their heads? If he had been satisfied with the positive acceptance of his results of the world survey and had joined his colleagues' works in nuclear physics, the controversy might not have arisen, or would have ended after a short time. Compton must have known that from Millikan's career, personality, fame, power, and the intense conviction of the truth of the atom-building theory, Millikan

53) See for the detail Kargon, *The Rise of Robert Millikan*, pp.154-157, de Maria and Russo, "Cosmic Ray Romancing", 243-248.

54) As to the expansion of the controversy by the press, see de Maria and Russo, "Cosmic Ray Romancing", 234-242, Kargon, *ibid.*, pp.154-155.

was the last man to change his mind or to quit the controversy before Compton himself did.

The atom-building theory was very important to Millikan both scientifically and religiously.⁵⁵⁾ Millikan thought that the principle of the Darwinian evolution theory would work in the world of matter in the same way as it works in religion and society. He expressed this view through the concept of continuous and endless creation of matter in the atom-building theory. As the theoretical bases for the atom-building theory, he took the Einstein formula on mass-energy transformation and Dirac's absorption formula; as a unique experimental evidence for it, he was proud of the values of absorption coefficients.⁵⁶⁾ He was satisfied that those theoretical and experimental bases accord well with his view that science should be reconciled with religion. As long as he was sure of the atom-building theory, the photon theory could never be dismissed. Thus, if Compton had had a good grasp of all these aspects, he would have stopped the meaningless battle much earlier, regardless of how annoyed he was by the press.

An answer to the question of why Compton did not stop the controversy earlier may be that he did not wish to do so. He was arguing over the latitude effect, the photon theory, the Lemaitre-Vallarta theory and other things about the nature of the cosmic-ray from 1933 till 1937, the remarkable period in the history of nuclear physics, during which physicists had indulged in studying and discussing the unexpected characteristics of the shower particles and finally discovered the completely new particles from positron to muon.⁵⁷⁾ To these important accomplishments in physics, Compton contributed nothing. He might not have had the ability and confidence to do well in the new field of research. To him, the controversy with Millikan, although it was distressing and tiresome, might have been a good and appropriate excuse for not rushing into the new field. On the other hand, it might have appeared fortunate to other physicists that Compton was playing a role of an opponent to such a troublesome man like Millikan on behalf of all of them. While Compton was dealing with Millikan, they could do what they had to do and longed to do without any hindrance.

The long battle between Compton and Millikan was over in 1937. In 1935, Millikan published the expanded revision of his book *The Electrons*, newly titled *Electrons(+ and -), Protons, Photons, Neutrons, Mesotrons, and Cosmic Rays*. In writing the chapters on cosmic rays and the latitude effect, he enhanced the role and parts of himself and his

55) See Galison, *How Experiments End*, pp.86-89 and de Maria and Russo, "Cosmic Ray Romancing", 214-216.

56) Millikan, "Evidence for the Continuous Creation", *Physics 14* (1928), 447-448.

57) See Galison, *How Experiments End*, chap.3.

collaborators and reduced markedly those of others including Compton and Clay. Even the name of "Compton" was out of sight in the pages. Compton and Millikan once more clashed acrimoniously. While Millikan continued publishing articles to degrade Compton's work, Compton prepared another article to clarify his contribution and informed Millikan of the plan. Both were extremely irritated by each other. One of them had to stop this unproductive and destructive squabble. It was not until 1937 that Compton, who was completely tired, realized the meaninglessness of the controversy and decided to end it by sending a letter to Millikan that he would not publish his article.⁵⁸⁾ It was the end of the war without a distinct winner or a loser.

Focusing on the controversy between the two famous American scientists in the early 1930s, I tried to show what the controversy actually was like and where the protagonists of the controversy stood along the working line of the physics in those days. Few historians of science were willing to look into the event with a historical microscope; they paid much attention on the debates over the shower particles for the same period. The event was recorded at best as an interesting episode which created a new popular image of scientists who can make a mistake, are fallible, and sometimes can lose their temper.⁵⁹⁾ It was casually inserted in the history of experimental nuclear physics beginning with the cosmic-ray showers.⁶⁰⁾

If it had been the five-year controversy about some very important theoretical or experimental results in our physics text today, they would have had a lot more interest in it. Compton is remembered by the Compton effect that he had discovered rather accidentally during the course of X-ray research, other than the latitude effect that he verified through the grand program organized for its own purpose. Some would even consider that he had wasted the valuable five years, a considerable amount of money, and the passion for a more productive work, just in order to add a sentence to the contemporary knowledge of the cosmic ray : "The cosmic ray is composed of charged particles as well as photons."

In place of concluding remarks, I will end with some questions. Did Compton actually waste his time in prolonging the controversy? Why would other physicists not interfere in the controversy? If Compton had joined the shower-particle research instead of exhausting himself in the controversy with Millikan, could he have made an important contribution to the studies in the nuclear physics? Didn't someone else, other than Compton, have to respond to Millikan anyway, when the latter explained

58) Kargon, *The Rise of Robert Millikan*, pp.158-161.

59) D. J. Kevles, *The Physicists : The History of a Scientific Community in Modern America* (New York : vintage books, 1979), pp.240-243.

60) Galison, *How Experiments End*, pp.93-94.

even the cosmic-ray shower as the phenomenon caused by the continuous interaction of the primary photons with atoms?⁶¹⁾ If there had been no one matching with Millikan, could the outstanding physicists in the United States, such as Anderson or Oppenheimer, who had played a major role in the great development of the nuclear physics through the 1930s, have whole-heartedly engaged in the research of the nuclear physics? These are all questions worth addressing about the Compton-Millikan controversy of the 1930's, the answers to which can be gathered, I believe, from the previous pages.

61) Millikan, "New Techniques in the Cosmic-Ray Field", *Phys. Rev.* 43 (1933), 662-663.