

Chapter 6 Shankland

1930 – 1976

In the fall of 1925, a young fellow from Willoughby, an eastern suburb of Cleveland, signed up for the mechanical engineering program at Case. Robert Sherwood Shankland (1908-1982) soon switched his major to physics, becoming a student of Professor Miller. Shankland remained connected with Case until his death. His lifelong interest in various aspects of acoustics, stemming from his work with Miller, manifested itself in his wartime underwater-sound research and later in his extensive studies of the acoustic properties of large concert halls and churches.

After an eighteen month stint in Washington at the National Bureau of Standards (as part of the radio-wave transmission research group), Shankland returned to Cleveland to work as an instructor in Miller's department and at the same time to complete a Master's degree. His 1933 thesis title was "The Dispersion of X-rays". It describes measurements made of the index of refraction of calcite for x-rays. The equipment, including an evacuated spectrometer, x-ray tube, and photographic detectors were of professional quality and the analysis of the data (including, of course, some curve-fitting with the Henrici analyzer) clearly presented. Shankland determined the dependence of the index of refraction on the wavelength of the x-rays, i.e. the "dispersion". The original of the thesis, with skillfully hand-drawn figures is part of the departmental archives. Perhaps not coincidentally, Shankland was to be looking at a very different aspect of x-rays three years later in his doctoral research.

Shankland entered the graduate program at the University of Chicago where he became a student of Arthur H. Compton. Compton had lectured at Case in 1927 and Shankland had decided at that time that this was the physicist with whom he would like to work. He spent four summers at Chicago, while still an instructor at Case, and then two full years in residence. One of his closest friends at Chicago was fellow grad-student and future Nobelist, Luis Alvarez. Starting with his arrival in Chicago, Shankland began to keep detailed personal journals, a custom he would continue for several decades. (The twenty volumes of these journals are, in 2005, in the possession of his family.) In the first of twenty volumes he writes how he was nervously waiting for the posting of the results of his doctoral oral examination (with Compton and Gale) when Alvarez came in with a long and sad face, feigning bad news – and then how they celebrated.

Shankland completed his doctorate in 1935, writing his dissertation on "The Photon Theory of Scattering." His results were published in the *Physical Review* in a paper entitled "An Apparent Failure of the Photon Theory of Scattering". (*Phys. Rev.* **49** 8 1936) Shankland returned to Case, grateful to Miller for holding a position for him. This was not easy at the beginning of the Depression, when it was very difficult to find any kind of job.

An aside on photons and the quantum theory of light. Physicists knew that light is a wave in which a combination of electric and magnetic fields carries energy through space, all beautifully described by Maxwell's equations of the 1870's. Then Einstein

came along in 1905 and explained the photoelectric effect, in which light shining upon a metal causes electrons to be knocked out of the metal. Einstein showed that light must be treated as bundles of energy called photons. Consequently, light may be described in two ways: as waves or as photons. Later it was found that ordinary things like electrons and protons also must be described both as waves and particles. Many physicists resisted these new ideas, but experiments, like the one done by Compton which we shall now describe, went a long way to clinching the argument. Even today, there are some who are, to say the least, uncomfortable with the wave-particle duality of quantum mechanics, relativity and other not-particularly-intuitive ideas in modern physics; we'll meet some of these "holdouts" later.

Compton and Compton Scattering

Twelve years before Shankland's experiment, Compton had reported his pioneering work on the scattering of x-rays by matter. He presented evidence that the process involved a quantum of electromagnetic radiation, the photon, interacting with a single loosely bound small electron in the atom. (*Phys Rev* **21** 483 1923) He argued that the photon has a well defined energy $h\nu$ and momentum $h\nu/c$ (ν is the frequency of the radiation, h Planck's constant, c the speed of light), and that both energy and momentum are conserved in the collision. This classic experiment appears today near the beginning of any "modern physics" textbook and is offered as evidence for both the quantum theory of light and of special relativity. Compton used conservation of momentum and energy, along with Einstein's relativistic expressions for the momentum and kinetic energy of the outgoing electron, to derive his famous formula: $\Delta\lambda = (2h/mc) \sin^2 \frac{1}{2} \theta$. (m is the mass of the electron.) This equation states that $\Delta\lambda$, the *change* in the wavelength of the scattered photon, depends only on θ , the angle through which it is deflected. (It is proportional to the "square of the sine of half the scattering angle".) Compton was able to test this prediction experimentally by measuring the wavelength of the incoming and outgoing radiations. (He used the well-established technique of "Bragg" scattering.)

This view of what we now call "Compton scattering" was quite innovative at the time, and alternative "classical" models suggested that the radiation would be absorbed by the atom, and an electron and longer wavelength radiation would later escape from the excited atom. Another model proposed that the target electron is an extended object and that the radiation observed might result from (in Compton's words) "the interference between the rays scattered by different parts of the electron".

Compton calculated not only the expected shift in wavelength, but also the probability that the photon would scatter into a given angular range. As both predictions were unambiguously supported by his measurements, the competing theories were rejected, and the quantum theory of the photon was given a strong boost.

Shankland and Compton Scattering

Compton's experiments did not, however, include any detection of the recoiling electron. Therefore, the young graduate student set out to further test the Compton theory

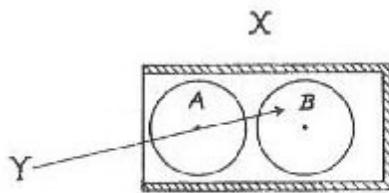


Fig. 6-1. Electron detector box.

by detecting the outgoing electron. Shankland knew that the Compton theory required that the photon and electron must appear at the same time and that there must be a well defined correlation between their directions. He used the new technique of "coincidence counters". A radioactive source (radon) provided the beam of energetic photons. Geiger-Müller counters were placed so as to catch both the outgoing photon and the recoil electron. The electron detector included two counters which had extremely thin walls and were placed one behind the other. (Fig. 6-1). An electronic circuit was devised which produced a "coincidence" signal only when both electron counters were hit. This greatly reduced the very large number of accidental electron counts. This signal was subsequently combined with one from the photon detector, so that all three counters must have been hit within an interval of about 0.3 milliseconds.

He used several targets (air, Al, paraffin, Be) and fixed the photon counter at $\theta=35^\circ$. In Fig. 6-2, the photon counters are labeled P and the recoil electron counters R. The radon source is at γ .

He placed the electron counter at first where the electrons were expected, and then at two positions where they are not expected: viz. in the correct plane but on the photon side, and then 90° out of the plane. He presents a table of results giving the expected number and the observed number of "triple coincidences" for the various configurations and targets. Typical numbers for observed/expected (in counts per hour) in three runs are: 2.4/23, 4.7/48, 14/69, with uncertainties on the observed counts of about 30%. Shankland concludes: "the photon theory in its present form does not agree with the experiments reported here."

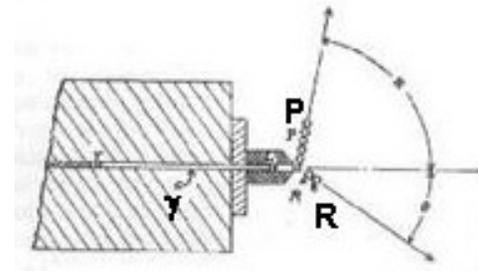


Fig. 6-2. Shankland's Compton scattering experiment.

He acknowledges Compton: "This experiment was suggested to the writer by Professor Arthur H. Compton and its completion has been possible because of his generosity and stimulating advice."

It would be interesting to learn how Compton reacted to this result, but no doubt he urged Shankland to pursue the matter further. One might also speculate about discussions between Shankland and his mentor, Miller, since each had now published experimental data which called into question an essential aspect of the new theoretical physics. Within 8 months, however, Shankland sent a short "Letter to the Editor" describing a new attempt, featuring a new configuration of the counters. (*Phys. Rev.* **50** 571 1936) (Fig. 6-

3) First, the electron detector was reduced from two counters to one. Second, the photon counter was fixed at 90° to the beam direction, and the single electron counter was placed either at the expected angle ($+\Theta$) or at the same angle, but on the wrong side of the beam ($-\Theta$). Then coincidences with the photon counter were recorded for these two positions and for target in place and target removed. The results: in counts per hour, [target in:

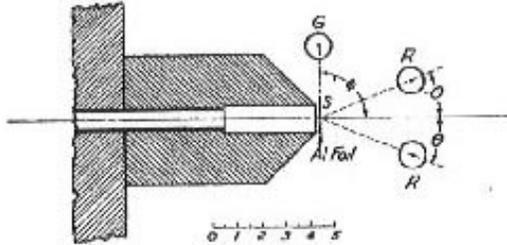


Fig. 6-3. The configuration that worked.

target out: 10.7 ± 4.4 on correct side and 12.5 ± 5.6 on wrong side]. Conclusion: “there is a coincidence in time between the appearance of a recoil electron and the scattered gamma ray which liberated it.” There is no mention of the results of the earlier experiment or what may have been wrong, although it is probable that his “triple coincidence” signal was faulty. The 28-year-old researcher, who was perhaps the first to do experiments involving the use of Planck’s constant in Cleveland, thus finessed a somewhat shaky start.

A longer paper ten months later presents a more detailed account of the ongoing experiment, including a quantitative discussion of uncertainties such as the effects of multiple scattering and accidental coincidences. (*Phys. Rev.* **52** 414 1937) In the introductory paragraph of this third paper, Shankland mentions that his earlier results did not support the Compton theory, but then he writes: “The publication of these findings aroused an active interest in the subject which resulted in several new experiments and theoretical discussions that have added greatly to the knowledge of these phenomena.” Our young researcher skillfully finds the bright side and moves on to his new results.

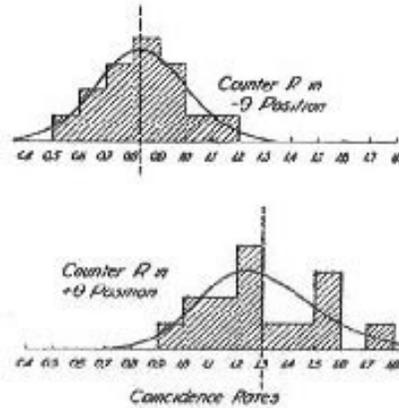


Fig. 6-4. Coincidence rates for wrong side (upper) and correct side (lower).

The revised experimental setup has the photon counter at 90° and the single electron counter at 22.5° or at the same angle on the wrong side. The 22.5° electron angle corresponds to a 90° scatter of a 350 keV Ra C gamma ray (i.e. photon). The average rates from 15 runs (about 200 coincidences) were, in counts per minute, (1.30 ± 0.10 for correct side and 0.83 ± 0.09 for wrong side), about a 5 standard deviation effect. For some reason, the “wrong side”, i.e. accidental, count is much higher here than that mentioned in the Letter to the Editor. Histograms of the number of coincidence counts for each run, for the “wrong” and “right” positions are shown in **Fig. 6-4**. The paper goes on for four more pages discussing the origins of the

high accidental rate and making comparisons with other researchers' results. The final paragraph states that "no time lag as great as 10^{-4} s can exist in the Compton scattering process, and ... the angular relationship given by the theory... is verified to within $\pm 20^\circ$ ". The young experimenter is pictured (standing) in **Fig. 6-5**.

In a recorded interview with Loyd S. Swenson, Jr. in 1974, Shankland commented on this work. Swenson was acting for the American Institute of Physics and its Niels Bohr Library Archives and the interview is part of the AIP history of physics collection. From the interview: "At first, we obtained results that seemed inconsistent with the Compton theory, and we were inclined to say that they supported the Bohr-Kramers-Slater theory, which ascribed a statistical view to the Compton interaction. But we found

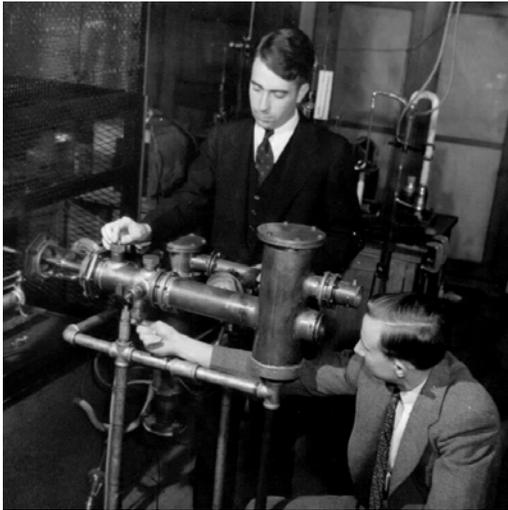


Fig. 6-5. Shankland (standing).

very soon that our counting rates were too high, and that we were experiencing what we now know as the dead-time of the counters, and we were missing a number of true coincidences. So when we used weaker sources of gamma rays, better circuits, then we got the coincidences that we reported." Having made an important contribution to the experimental basis of the photon quantum theory, Shankland seemed ready to move on to other pursuits.

In an interesting combination of his work with Geiger counters and his work with Miller, Shankland used the Henrici analyzer in the Fourier analyses of oscilloscope traces of pulse shapes for different counter designs and circuits.

Shankland in World War II

For the almost fifteen years that Shankland had studied under and worked with Dayton Miller, he had participated to some extent in his mentor's research in musical and architectural acoustics. He describes, for example, his tedious efforts to produce phonodeik traces which were up to Miller's high standards. It was only natural that, when most academic physicists found ways to serve their nation in World War II, Shankland should find himself working with the US Navy on underwater sound detection. He worked for various government agencies from 1942 through to the mid-1950's. Highlights of this work were the year he spent (1943) as the representative in England of the US Office of Scientific Research and Development and the time he spent as director of the Columbia University headquarters of the Underwater Sound Reference Laboratories.

Shankland and Architectural Acoustics

Shankland developed an interest in the acoustic properties of such large enclosures as churches and concert halls. As a well known author on acoustics, Miller collaborated with architects, preachers, and musicians on how best to design and outfit a hall for ideal acoustics. Shankland would eventually be equally recognized as a knowledgeable consultant. The main goal of this work is to have just the right amount of reverberation to provide richness to the sound without the garbling that too many echoes or too persistent a sound will cause. Another desired property is the ability of musicians on a stage, for example, to hear themselves and one another. Shankland's principal contribution to this, as it is sometimes described, "black art" was to visit scores of halls and to determine quantitatively the acoustic response to standard sound intensities. He describes this work (once again from the AIP interview tape transcript) as the "accumulation of as much information as we can about buildings that are successful". And this he did, traveling with his wife, Hilda, to make measurements all over the United States and Europe.

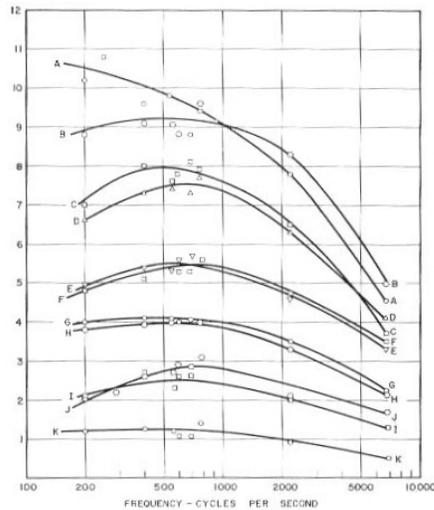


Fig. 6-6. Reverberation times vs frequency for 11 churches.

Carlo Opera Theater in Naples. The floor plan of the long, highly reflective interior of "St. Pauls outside the Walls" is shown in **Fig. 6-7**. Shankland even went so far as to have sound absorbing curtains and carpeting installed in one of the smaller halls, successfully reducing long high-frequency reverberation times, which he said caused confusion. He remarks that long reverberation times are desirable in large halls, but not necessarily in smaller ones. Furthermore, he points out that reflected sounds from directions in the horizontal plane including the source and the listener are preferable to those bouncing off floors and ceilings. (*J. Acous. Soc. of Amer.* **43** 426 1968 and **50** 389 1971). An extensive article summarizing the measurements made during his European trips appeared in

In Chapter 12, we shall describe how Shankland and his young colleague, Arthur Benade, would contribute in the 1950's to plans for the re-designing of Severance Hall, the home of the Cleveland Orchestra. Recall that Miller had participated in the original acoustical design in 1931.

At the 1967 meeting of the Acoustical Society of America in New York, Shankland presented a paper entitled "Quality of Reverberation". He discussed the results of measurements of reverberation times as a function of frequency for a dozen famous churches and theaters in Italy. Reverberation times in seconds are plotted against frequency from 200 to 7000 Hz in **Fig. 6-6**. They range from ten seconds in the basilica of San Paulo fuori le Mura – the top curve - down to only one second in the San

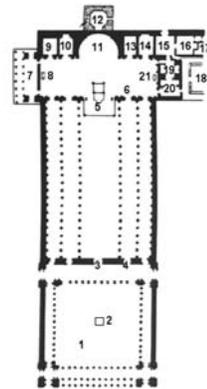


Fig. 6-7. Floorplan of San Paulo in Rome.

the Sigma Chi journal: *Amer. Scientist* **60** 201 1972.

In 1973 the widely circulated magazine of the AIP, *Physics Today*, featured a cover-article by Shankland on the acoustical properties of open-air classical Greek theaters. (*Physics Today* October 1973). Illustrated in this article are "articulation scores" plotted against distance from center of stage to listener. The articulation score is the percent of words spoken at the stage which are understood by the listener (English in this case, not Greek!)

Another Shankland quotation from the Swenson interview: "I have a great body of data and information about the acoustics of buildings that I hope to use to write a book on architectural acoustics one of these days. I think it will be a book that has a lot in it that the conventional books do not have, because these are largely based on buildings in the United States, and fairly recent buildings." There are twelve Shankland papers in the *Journal of the Acoustical Society* on these studies. I don't know if Shankland began organizing this book; his health seemed to be quite good during the years after the AIP interview. His files on the subject, now in the departmental archives, are extensive, but there is no sign of a draft.

Accelerator Physics at Berkeley

Shankland spent the summer of 1946 at the Radiation Laboratory of the University of California at Berkeley, doing a proton-proton scattering experiment at the 37-inch synchrocyclotron. This accelerator-based program, mounted so quickly after the end of the war, would lead the race in the 1950's toward higher and higher energy machines. The development of accelerators and their associated particle detectors would make possible today's picture of particles and forces: a.k.a. the "Standard Model."

The Berkeley paper appeared in the *Physical Review*. Shankland's collaborators included Robert R. Wilson (future Nobelist from Cornell). They presented the differential scattering cross section for 14 MeV protons incident on protons. (*This means they measured the probability that a proton will scatter into a given angular range when it bounces off another proton. The resulting angular distribution leads to an understanding of the forces between the protons. There will be a more detailed description of scattering experiments in Chapter 9.*) The protons were incident on a thin target of nylon, and the two outgoing protons were detected by proportional counters as indicated in the sketch in **Fig. 6-8**. Shankland's main contribution was his expertise on the use of coincidence counters. (*Phys. Rev.* **72** 1131 1947).

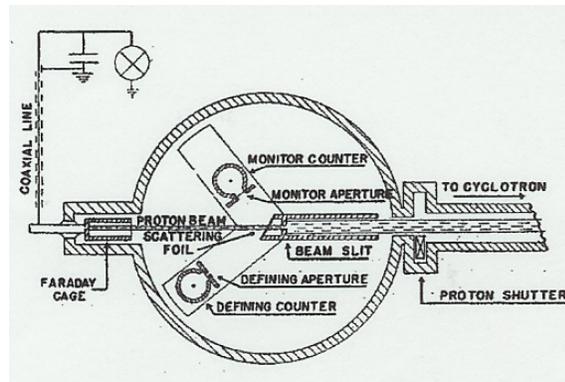


Fig. 6-8. Proton-proton scattering at Berkeley accelerator.

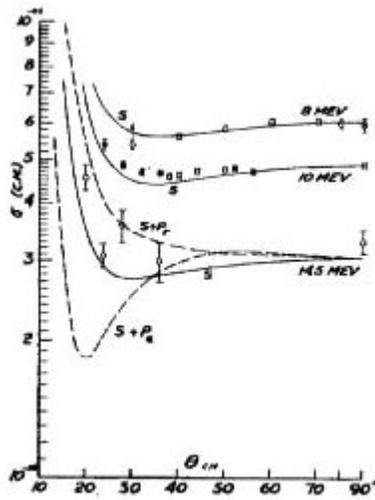


Fig. 6-9. Angular distributions for proton proton scattering.

At these energies, the two equal mass protons leave the target at 90° from one another, so the counters were placed at several pairs of orthogonal angles. The results are shown by the 14.5 MeV data set of **Fig. 6-9** (beneath two sets at lower energies measured by other experimenters). The three curves are calculations by Shankland's Case colleague, Leslie L. Foldy, based on a square-well potential with range 2.8×10^{-13} cm and a depth of 10.5 MeV. They include S-wave scattering (solid), S plus P-wave attractive (lower dashed) and S plus P-wave repulsive (upper dashed). If one just counts the number of standard deviations separating the points from the curves, the S and the S+P repulsive are about equally good. This experiment was one of the earliest attempts to get at the nucleon-nucleon force by scattering experiments. Foldy's work on this and many other theoretical topics will be described in Chapter 9.

Aside on S waves, etc. When two particles collide, they can have orbital angular momentum, like two ballroom dancers. Because of quantum mechanics, the angular momentum can take on only certain values. The lowest value, zero, is called S-wave scattering, the next value, $h/2\pi$ (h is Planck's constant), is called P-wave scattering. (The S,P,D,F letters come from archaic spectroscopic notation – sharp, principal, diffuse, and fine.) If multiple values of the angular momentum contribute to the interaction, they can interfere with one-another (quantum-mechanically), and produce a characteristic pattern in the differential cross-section, like the big dips in the curves in Fig. 6-9.

In the 1950's, Shankland was a physics consultant at the Phillips Petroleum Company's Materials Testing Reactor in Idaho Falls, where he produced a series of papers on neutron cross-sections. Between 1956 and 1958 he participated in experiments at that reactor. Total cross-sections for neutron interactions in carbon and chlorine were measured using a fast chopper to define the neutron energies up to 15 keV.

A chopper is a set of two co-axial spinning disks with holes in each disk. The positions of the holes are offset from one another so that they permit the passage only of particles within a certain range of speeds. These devices were used to create beams of neutrons with a fixed energy, much as bending magnets are used to create monoenergetic beams of charged particles.

Shankland and Miller's Ether Drift

In the 1974 AIP interview, Shankland also discussed his connection with the Miller ether-drift experiments (which we described at length in Chapter 4). The cover page of the Miller article in the *Reviews of Modern Physics*, including the dedication by Miller to Shankland, is shown in **Fig. 6-10**. The following italicized paragraph is a condensed version of part of the AIP interview.

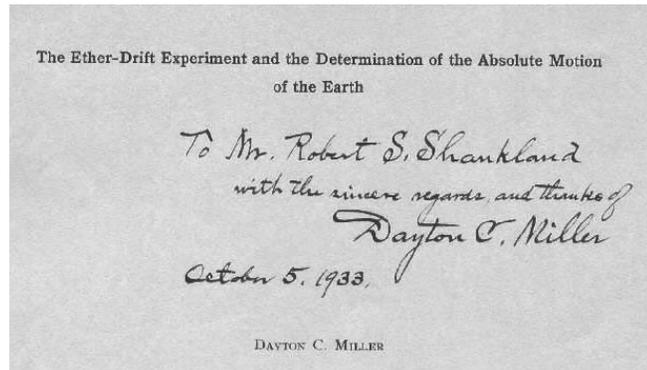


Fig. 6-10. Cover page of Miller's "final" ether-drift paper.

I never worked with Miller when he was making measurements with his interferometer. Those were made at Mt. Wilson and finished during my freshman year. I did help him with some aspects of his final write-up of the paper, but I must say that I never personally could accept Miller's view that it disagreed with relativity. I was absolutely sure that Miller was honest in everything he did, and it was a real puzzle in my mind for many, many years, as to why it was that this periodic effect was there. And I finally decided to spend some time seeing if I could straighten it out, with the help of McCuskey and Kuerti, and with the encouragement of Einstein. We worked away at it, and this was in accord with what Dr. Miller wanted, because shortly before he died, he gave me a great pile of data sheets which I still have, and he kind of pushed them at me and said, "Well, there are the Mt. Wilson observations. You keep them. And you can either burn them up or study them, whichever you think best." This must have been either in January of '41 or shortly before. For years I just had them locked in a closet, but then over a period of nearly 15 years, I would get letters from very distinguished physicists asking me what I thought about Miller's work. So instead of burning them up, we studied them. Einstein wrote me a very nice letter when we got through. He didn't see the final printed version; he died a month before, but he saw every draft.

The resulting paper, "New Analysis of the Interferometer Observations of Dayton C. Miller", authored by Shankland, S. W. McCuskey (chair of the Case astronomy department), F.C. Leone (professor of statistics and mathematics), and Gustav Kuerti (professor of aeronautical engineering and mathematics) appeared in the *Reviews of Modern Physics* (*Rev. Mod. Phys.* **27** 167 1955). These four authors were the most qualified members of Case Institute's faculty to undertake this project. The authors first point out that the Miller measurements made in Cleveland showed very little effect, and that the primary evidence for ether-drift was in the Mt. Wilson data. Miller's raw data consist of many pages, each with twenty rows of sixteen numbers corresponding to the sixteen fringe-shift observations in each of 20 turns of the interferometer. There are data taken at all times of day and at the four seasons of the year. The pages are frequently annotated

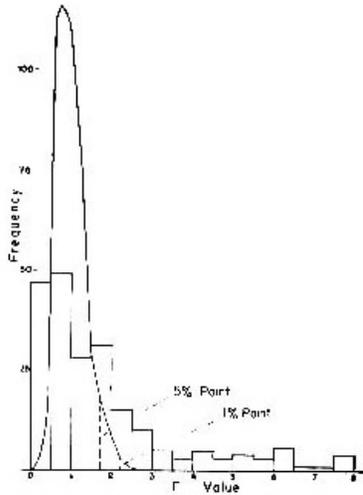


Fig. 6-11. Statistical test for randomness in Miller data.

with “viewing conditions”, weather, temperature, etc. Miller’s analyses and his interpretation of them were described above in Chapter 4.

Shankland *et al.* first determined the degree of randomness of the entries. For each sheet, they calculated a statistical factor proportional to the sum of the squares of the deviations from the mean. The data were rewritten in units of one twentieth of a fringe, this being assumed to be a reasonable least count. Statistical theory gives the expected distribution of this “randomness factor”. In **Fig. 6-11** are shown the randomness for 216 sets of data and the theoretical curve for a random distribution. The conclusion is that structure in the data comes from something other than statistical fluctuations, since a full 36% of the data-points fall in the region on the right where only 5% should lie if the variations were random.

Another demonstration of a non-random signal in the second harmonic (i.e. the presence of a full 360° sine-wave in the fringe shift for a complete turn of the interferometer), is shown in **Fig. 6-12**. Here, the average values of the fringe shift for each of the 16 positions of the interferometer (averaged over a complete sheet or 20 turns) are shown for twenty sheets from the July set. While there is very large scatter in the data, the average of the averages (the large black circles) does show a sine-wave form with amplitude about 0.03 fringe. Similar plots for the other three “seasons” are constructed, and, folded about 180° , are shown in **Fig. 6-13**. Neither Miller nor the four authors could find any argument for the variation in phase among these four curves (i.e., why are they shifted horizontally with respect to one another?) As Miller had done, the authors sought a way that a “cosmic solution”, e.g. motion through the ether of the whole solar

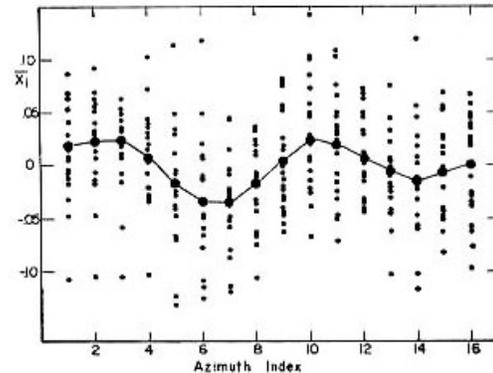


Fig. 6-12. Compilation of second harmonic fringe shifts.

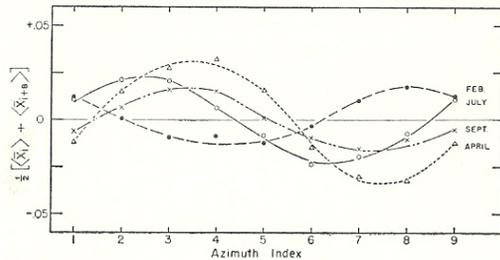


Fig. 6-13. Second harmonic signal for four seasons.

system, might fit the data. They conclude that no consistent solution of this type can be extracted from the data.

The goal, now, is to determine the cause of this residual non-random structure. They turn therefore to a search for systematic mechanical or thermal causes. A mechanical analysis was made of the possible oscillatory motion of the heavy steel cross-beams which

rested on a wooden box floating in mercury. They wanted to determine if some sort of periodic “rocking of the boat” might affect the distances between the mirrors (tilting of a support beam might cause its two arms to sag differently). Knowing the geometry and mass distribution of the system and the restoring forces, they calculated the natural frequency of the rocking motion. This came out as 1.2 s to 1.4 s, so any such motion would have been averaged out over the typically 50-second rotation of the interferometer arms.

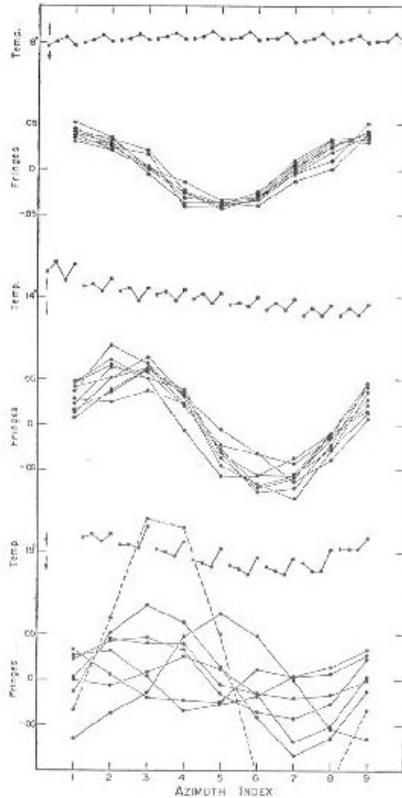


Fig. 6-14. Temperature variations shown with corresponding fringe shift signals.

Beneath each of these three sets of temperature data is a plot of the fringe shifts observed in the corresponding set of runs. The ordinate scale markers are at plus and minus 0.05 of a fringe. It is clear that the more constant the temperature, the smaller the fringe-shifts. The dashed curve in the bottom set shows how bad things can get when sunlight falls on the interferometer. Calculations were made to determine by how much the temperature should change within the glass-enclosed interferometer arms as a result of a given temperature gradient across the hut. The numbers are consistent with the observed shifts. The authors would like to have established a clear, one-to-one, relationship between measured temperatures and both phase and amplitude observations, but they have to settle for a more general conclusion: *i.e.* that the actual thermal conditions were *sufficient* to cause the observed effects. I quote an entire paragraph in this regard:

Next, they searched for possible systematic thermal effects, and here, patient reader, is where they find the answer. Miller himself was very much aware of the importance of avoiding thermal expansions and contractions of the steel arms of the interferometer and changes in the index of refraction of the air between the mirrors. Miller had even purposely introduced electric heaters to establish a temperature gradient across the device and observed a resulting fringe-shift signal of up to twenty-times larger than the 0.03 fringe “ether signal”.

Miller provided on each sheet the temperature of the air at each of the four walls of the hut. The authors searched for those sets of data for which the temperature was relatively uniform and constant through the viewing period. Readings taken between midnight and dawn provided the best conditions. **Fig. 6-14** shows the correlation between temperature stability and the amount of fringe-shift observed in three late night sessions. The figure is a bit confusing. The little zig-zag sets, each with four data points, are the temperature readings on the four walls of the hut, taken at fixed intervals during the five-hour period of the runs. The little arrows to the left indicate plus and minus one degree Celsius. The top set (from Cleveland measurements) shows the least

“Thus Miller’s experiments in 1923 do not rule out the possibility of attributing the remaining systematic effects in the Mount Wilson data, which are most prominent in the second harmonic A_2 and to a lesser degree in the first harmonic A_1 , to temperature causes. In what follows, we shall interpret the systematic effects on this basis but must admit that a direct and general quantitative correlation between amplitude and phase of the observed second harmonic, on the one hand and the thermal conditions in the observation hut on the other hand could not be established. The reason for this failure lies in the inherent inadequacy, for our purpose, of the temperature data available.” In short: not enough information to tie it down quantitatively!

This careful reanalysis of the Miller data satisfied the authors and the physics community-at-large that Miller’s effect was real, but thermal in origin. Thus the Miller experiment joins the many others, performed in the twentieth century and with increasingly sophisticated techniques, in which no evidence for ether-drift is observed. Included in these later ether-drift searches were those done in the 1920's by Michelson himself.

Shankland Discusses Michelson-Morley and Miller with Einstein

Shankland visited Albert Einstein in his Princeton home on five occasions, the first being in February of 1950, the last in 1954. In 1963, he published an article in the *American Journal of Physics* describing these meetings. There were three major topics in their discussions, the Michelson Morley experiment and its influence on the development of the special theory of relativity, the subsequent observation by Dayton Miller of a systematic fringe-shift in his repetition of the ether drift experiment, and some general remarks by Einstein on quantum theory. Ten years later, Shankland sent a second paper to that journal. In his introduction he says that in the earlier paper the discussions "were published almost verbatim with but little comment by me. They have since been referred to in several articles on the history of physics, so it now seems appropriate to supplement the first publication by a more complete discussion of certain statements made to me by Prof. Einstein."

Shankland says that at the time of the first visit, Einstein "was unacquainted with me and may possibly have wondered if I had not come as the successor of Prof. Dayton C. Miller at Case to talk about Miller's 'aether drift' experiments at Mount Wilson." Recall that Shankland was only the fourth in the line of Case chairmen, after Michelson, Reid, and Miller. "When Prof. Einstein realized that I had not come as an advocate for Miller's results his attitude became less formal and our conversations were much more relaxed." Nevertheless, Shankland adds that "when he (Einstein) learned of Miller's result he traveled to Cleveland to see him and they had a long discussion about the Mount Wilson experiments". When I looked through the archives of the *Cleveland Plain Dealer* for references to Einstein, I found a front page article on Einstein's visit. He was in town on a Zionist fund-raising tour in the company of Chaim Weizman, the physicist who would become Israel's first president. This was the same time as the meeting with Miller. The department still has Miller's guestbook with Einstein's signature, dated 1922. (It was also Case graduation day, so Miller must have been very busy.)

Shankland remarks "when we (*i.e. he, McCuskey, Leone and Kuerti*) finally found the cause of Miller's periodic fringe shifts to be temperature gradients across the interferometer, Einstein was genuinely pleased, in fact, wrote me a fine letter on the subject." The letter was reproduced in an article by Shankland, "Michelson's Role in the Development of Relativity", which appeared in October of 1973. (This article in *Applied Optics* was based on the "Naval Academy Lecture" given by Shankland at Annapolis in May of that year. The lecture was given as part of the celebration of the 100th anniversary of Michelson's graduation from Annapolis. *Applied Optics* **12** 2280 1973.)

August 31, 1954

Dear Dr. Shankland,

I thank you very much for sending me your careful study about the Miller experiments. Those experiments, conducted with so much care, merit, of course, a very careful statistical investigation. This is more so as the existence of a not trivial positive effect would affect very deeply the fundament of theoretical physics as it is presently accepted.

You have shown convincingly that the observed effect is outside the range of accidental deviations and must, therefore, have a systematic cause. You made it quite probable that this systematic cause has nothing to do with 'ether-wind', but has to do with differences of temperature of the air traversed by the two light bundles which produced the bands of interference. Such an effect is indeed practically inevitable if the walls of the laboratory room have a not negligible difference in temperature.

It is one of the cases where the systematic errors are increasing quickly with the dimension of the apparatus.

Congratulating you and your colleagues on your valuable contribution to our knowledge, I am

With kind regards,

A. Einstein (signed)

The letter came into the possession of Shankland's second wife, Eleanor, who in 2000 generously donated it and three other Einstein artifacts to the University. It was sold at auction and the proceeds were made available to the physics department for the support of graduate students .

Concerning the Michelson-Morley result, Shankland states that Einstein's comments over the course of their several discussions were "not entirely consistent", at least as to when and how he had learned of the null result, and what role it played during the period when he was thinking about special relativity.

Finally, concerning Einstein's opinions on quantum mechanics, Shankland lists a series of one-sentence quotations, which he says are as accurate as he could make them, having carefully written them down immediately after his chats. Three short examples which make his position clear: "On quantum theory I am in the opposition." "The ψ

functions do not represent reality." "Bohr always speaks *ex cathedra*." "Conversations with Albert Einstein" *Amer. J. Phys.* **31** 47 1963. "Conversations with Albert Einstein, II" *Amer. J. Phys.* **41** 895 1973. Included in Shankland's personal journals are eleven pages describing his 1950 visit with Einstein, presumably written on the same day. The text is much more detailed and less polished than the papers published over a decade later.

The "Return" of Miller's ether drift, a digression

Sometime in 1998, I was telephoned by the editor of a magazine called *Twenty-first Century Science and Technology*. She had been in contact with the CWRU Archives, and was referred to me. They were planning an article about Dayton C. Miller and were looking for some photos to illustrate it. During the renovation in 1995 of our (i.e. Miller's) building, my colleague Bill Gordon and I gathered up quite a collection of old apparatus from the attic, as well as several drawers of files. I had randomly glanced through some of the documents, and I knew that we did indeed have a few gems, such as Miller's accounts books, his guest book with Einstein's signature, hundreds of lantern slides, etc. Up to that time, my knowledge of Miller was little more than a portrait on the wall.

I sent a few photos of Miller and his interferometer. The CWRU archives did likewise. I was thanked by the editor, Marjorie Hecht, who promised to send a copy of the magazine. The handsome, glossy product arrived a few months later. There was Miller on the cover; and the headline read "Michelson-Morley-Miller: The Coverup" The 25-page article described the Miller experiments in detail, presenting them as proof that the ether does exist and that Einstein's relativity theory is wrong. They mention, in a section titled "The Debunkers", the Shankland, *et al.* 1955 paper and the correspondence between Shankland and Einstein, implying that these two fellows conspired to cover up the Miller results. The magazine, it turns out, was published by the organization of Lyndon Larouche, the fellow who has built his several presidential campaigns on the exposure of a wide array of evil plots against the American people, including, it seems, special relativity. The editor with whom I had corresponded is Mr. Larouche's wife.

This magazine incident was a useful learning experience. In 2000 I received an enquiry by a gentleman from Oregon concerning Miller. The fellow was planning a trip to Cleveland and asked if any of the original Miller data were available. I did an internet search for references to the prospective visitor, and found that, as the director of an institute specializing in organics research, he had lectured and published on Miller, the ether, and relativity. Organics, the study of the properties of an energy field which surrounds the human brain, apparently needs a medium of some sort.

When he came to Cleveland, I asked him why he was interested in the Miller data. He said that he would reanalyze it using modern techniques. He was aware of the Shankland reanalysis paper, but dismissed it as biased. After he left, I searched through the dozen large file drawers of Shankland papers. The Miller data sheets were there all along, hidden among some architectural acoustics papers. I have since turned them over to the

CWRU Archives so that anyone interested may access them. Anyone wanting to tease out, once again, the tiny and random-phased signal from those numbers had best study the Shankland paper first. It wouldn't hurt to check out recent results from repetitions of the MM experiment using resonant microwave cavities. These report no effect at the one part in 10^{13} level. (Lipa *et al. Phys. Rev. Lett.* **90** 060403 2003). Even Miller's small ether-drift would raise havoc with today's global positioning system.

Shankland edits the Compton papers

In 1973, Shankland edited a collection of selected papers by his mentor: *Scientific Papers of Arthur Holly Compton: X-Ray and Other Studies* (University of Chicago Press). This 777-page compilation, including an extensive introduction, appendices, and bibliography, was received by the history of physics community as a valuable contribution. Roger H. Stuewer, historian of science at the University of Minnesota, reviewed the work and congratulated Shankland on a compilation from which the reader "can learn a great deal about the way research in physics is actually pursued." For those who may be interested in this project, an extensive file of Shankland's notes and correspondence on the subject may be found in the CWRU Physics Archives.



Fig. 6-15 is a photograph taken on the day a new portrait of Shankland was dedicated. Participating are Chairman Frederick Reines, Case President T. Keith Glennan, Shankland, and theorist Leslie L. Foldy. It hangs today in Miller's big lecture hall.

Fig. 6-15. Reines, Glennan, Shankland, Foldy.

Robert Shankland retired in 1976, but continued to work on his papers until his death in 1982. His wife, Eleanor, is well known as an artist and, as mentioned above, a loyal friend of the university. She has done a series of drawings of the buildings on the campus, among which is this one of the Rockefeller Building. It is easy to see the artist as she sits at her easel, but you have to look closely to find Bob Shankland at the window of his office.

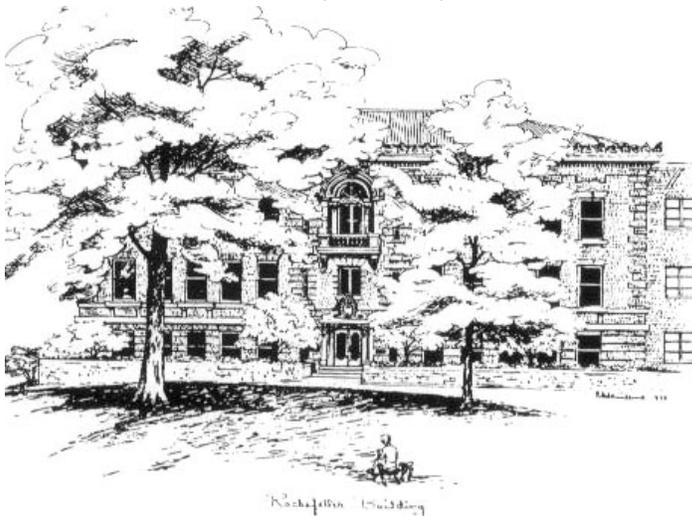


Fig. 6-16. Eleanor Shankland's drawing of Rockefeller.