VI. William Duane

"The unit I was using in 1914 (was defined as) the intensity of roentgen-radiation that produces the electrostatic unit of ionization current per cubic centimeter of air under normal conditions of pressure and temperature."[158]

William Duane was born in Philadelphia on 17 February 1872; he was the son of Reverend Charles William Duane, rector of the Saint Andrew's Episcopal Church of West Philadelphia, and of his second wife, Emma Cushman Lincoln Duane. On his father's side, he was a direct descendant of Benjamin Franklin (1706–1790): Sarah (Franklin) Bache (1743–1810), Deborah (Bache) Duane (1781–1863), William John Duane (1808–1882), Charles William Duane (1837–1910).

Young Duane attended private schools in Philadelphia, then registered at the University of Pennsylvania and studied mathematics (including quaternions). As a stripling, he completed the prescribed curriculum studies of the Philadelphia Musical Academy and graduated in the organ course; he earned pocket money by playing the organ at various church activities (Fig. VI-1). In 1892, he received his Bachelor of Arts degree as valedictorian of his class; in 1893 he earned another B.A. degree at Harvard, where he was retained as an assistant in the department of physics. The elder Duane had moved his family to Boston and had become rector of the historical Christ Church. Duane worked with Professor John Trowbridge (1843–1923) and co-authored a paper on the velocity of electric waves on wires. In 1895 he received his *Magistri in Artibus* degree (Fig. VI-2).

Duane went to Göttingen and Berlin as a beneficiary of the Tyndall Fellowship; he studied primarily under Walther Hermann Nerst (1864–1941), professor of physical chemistry (Nobel, 1921), wrote three papers on magnetic fields and one on thermal chains; he followed the courses on theoretical physics of Planck, who graciously acknowledged Duane's gifts ("...ich habe dabei öfters Gelegenheit gehabt, seine gründliche Begabung und seinen gewissenschafter Fleiss zu bemerke"). Duane defended successfully his thesis, "*Ueber Elcktrolytische Thermöketten*," and received his *Philosophie Doctoris*, magna cum laude, from the University of Berlin in 1897. (Fig. VI-3.) As a special distinction to the young American scholar, a summary of this "laudable document of erudition and penetration" was presented to the German Imperial Academy of Science. Duane was innately gifted, excellently educated and trained, and moreover, remarkably dedicated; he became an important protagonist in the unfolding of theoretical nuclear concepts and played a significant role in the development of radiotherapy in the United States.

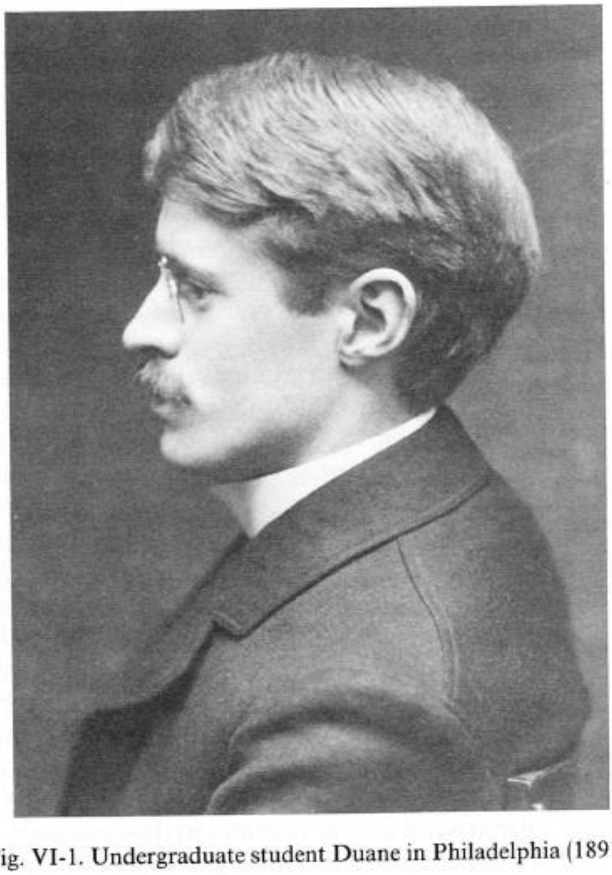

Fig. VI-1. Undergraduate student Duane in Philadelphia (1891).

Fig. VI-2. Bachelor of Arts Duane in Boston (1893).

After completion of his work in Berlin, Duane returned home and accepted a position as the first professor of physics at the University of Colorado in Boulder. The challenge of a small faculty and the freedom to search must have attracted the young idealist, but certainly also, as suggested by Professor Albert Allen Bartlett (1923–), he was attracted by the spirit of *the West*.[27] Through the years, others have felt the irresistible magic of fantastic rocks, dancing waters, rugged canyons, and a distant view that gives wings to the imagination in the Rocky Mountains.

Duane brought to the University of Colorado the high spirit of teaching of which he was a product; students of physics were now given an opportunity to investigate. Recently, Guglielmo Marconi (1874–1937) had succeeded in sending wireless signals over distances of 20 kilometers. Working under Duane's direction, the students of the University of Colorado were able to send and receive signals from one end to the other of the 100-foot-long Hale Building and then between Hale and Main (1899). (Fig. VI-4.)

On 27 December 1899 in Philadelphia, Dr. William Duane married Caroline Elise Ravenel of Charleston, South Carolina; she was the daughter of Samuel Prioleau Ravenel and of Margaretta Fleming (widow of Parker) Ravenel. The newlyweds settled in Boulder, Colorado in a beautiful home designed by Henry Hobson Richardson. Soon two baby boys, William, Jr. and Arthur Ravenel, enlivened the Duanes' household at 541 Highland Street; the house where they were born is extant (Fig. VI-5). Duane was an early enthusiast of the automobile and received attention from the students as one of the first to ride in a horseless carriage around the campus and in the mountains.

Professor Duane built up apparatus for experimental work in physical chemistry but soon returned to his interest in electromagnetism. He developed and obtained patent rights (No. 690248) for *synchronizing systems*, a device to permit multiple simultaneous telegraphy (multiplex telegraph).

As he completed his sixth year of service to the University of Colorado, Duane took the option of spending the seventh, or sabbatical year, abroad. He had been accepted to do research in the *Laboratoire de Physique Generale*, which the University of Paris had put at the disposal of Pierre Curie, the new professor of the Faculty of Sciences. Appropriately the laboratories were situated away from the Sorbonne, across the street from the *Jardin des Plantes*. The Duanes took lodging at 53 rue Notre Dame des Champs, they lived a short distance from the Luxembourg gardens, a paradise for the children as well as for adults. The walk to work was long but most pleasant through the Luxembourg, past the Pantheon, and to Monge; the alternative was the horsedrawn omnibus through the boulevards Montparnasse and Port Royal. The proximity of the laboratories to the city's wholesale wine market must have been a source of noon hour distraction. (Fig. VI-6.)

In Paris, Duane enjoyed great freedom in his work; he studied the ionization of air in the presence of radium emanation (radon). Pierre Curie, much against his own inclinations, had to devote time to the customary interviews before he was elected to the Academie de Sciences, and his Chief of Laboratories had to take time out to deliver their baby daughter, Eve. In addition, the Curies had to prepare for a trip to Stockholm

Fig. VI-3. Tyndall Graduate Fellow Duane in Berlin (1896).

to receive the 1903 Nobel Prize. Nevertheless, Curie was attentive to the needs of his young colleague, arranged for his work to be reported to the Academy,[155] and for it to be published in the *Journal de Physique*.[159] In this paper, Duane sketched his apparatus for radium emanation extraction (Fig. VI-7) and also first presented (1905) the *wall effect* of closed chambers on ionization. Before Duane had completed his year in Paris, Pierre Curie wished for his return ("Je serai très heureux de vous avoir de nouveau dans mon laboratoire si vous decidez jamais faire un nouveau sejour en France").

Before he returned to the United States, Duane spent three months in Cambridge, England. Joseph John Thomson (1856–1940) (Nobel, 1906) graciously offered him the hospitality of the Cavendish Laboratories. The Duanes were invited to Holinleigh on West Road; they were charmed by the college gardens and were met by Professor Thomson on the Hall steps for dinner at Trinity.

In the fall of 1905, Professor Duane was back at work in Boulder, Colorado. One of his faithful associates, Dr. Charles A. Lory (1872–1969), had kept the fires going during his absence.⋆ Duane resumed his academic activities; he was also very active in a town and gown scientific society and lectured on such subjects as *Some Great Truths of Astronomy* at the First Congregational Church. He had remained an accomplished organist and played regularly for services and recitals at the First Presbyterian Church.

Shortly after their return, the Duanes heard from Madame Curie: her husband had applied for a grant from the Carnegie Foundation, which they hoped would make it possible for Duane to return to Paris. In April 1906 Pierre Curie met his untimely death; this undoubtedly postponed the trip for another year. In September Mme. Curie let Duane know that Carnegie had granted their request and that the opportunity was opened for him to continue his research on radioactivity in her laboratories. An official appointment was later offered under an agreement between Carnegie and the Rector of the University of Paris; space and required equipment were made available. Thus, in 1907, after completing two additional academic years, Duane left Colorado.

Fig. VI-4. Professor of Physics Duane, University of Colorado (1900).

Fig. VI-5. The Duane household in Boulder, Colorado (1905).

The Duanes enjoyed their return to Paris with two boys of school age. Duane resumed studies of α-rays and of heat and electricity resulting from radioactivity; he collaborated closely with André Louis Debierne (1874–1949), the discoverer of actinium. One of Duane's published papers, in collaboration with Albert Laborde,[164] was concerned with quantitative measures of radium emanation.⋆ Ten of his works were the subject of formal communications to the French Academy of Sciences.

Toward the end of 1908, Duane learned that Ernest Rutherford (1871–1937) was about to receive the Nobel Prize and promptly wrote a letter of congratulations to his eminent colleague at McGill University ("As you know"—answered Rutherford—"the news often leaks out prematurely and sometimes incorrectly.... Thank you for your kind congratulations and trust that I shall deserve them"). The rumors proved to be accurate that time. Two other children were born to the Duanes during their second sojourn in Paris, but Mrs. Duane preferred not to deliver them in Paris; Prioleau was born in London (1909), and Margaretta Clarissa in Philadelphia, the city of her paternal ancestors.

Duane's research work in Paris lasted six years. Without suspecting it, Duane was contributing to the initiation of an institutional scientific research tradi-

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⋆ See Subject Notes on page 183.

tion that was to rise for the next decades and culminate in the discovery of artificial radioactivity and in nuclear fission. Meanwhile, amidst great intellectual excitement, American institutions were hastily catching up with the new development in physics. The Standard Chemical Company of Pittsburgh wished to secure Duane's talents. Francis Carter Wood (1869–1951) made an offer from the George Crocker Fund for work at Columbia University. Duane decided to accept the opportunity offered by Professor of Surgery John Collins Warren (1842–1927) on behalf of the Cancer Commission of Harvard University; he submitted an outline for the development of a Radium ("or Radiation") Institute, including departments of physics, chemistry, and biology, plans for a library, publications, public relations, a section of measures and standards, and a department of surgery and radiotherapeutics to include a hospital in the style of the Collis P. Huntington Memorial Hospital.

An important initial activity was the building of a radium emanation plant[157] (Fig. VI-8); Duane's model adopted features previously utilized by Debierne and Rutherford. Work at the Radium Institutes of Paris and London had already shown the pragmatic advantage of using radon rather than radium element; in addition, the radiophysiologic effects had been observed and utilized. At first the *radon* was collected in vials; later Duane conceived the idea of concentrating it in capillary glass tubes that could be cut in small sections, introduced into tumors, and the short life radon source left to decay. Duane's expertise was also utilized for the building of another of automatic extraction plant at the Memorial Hospital of New York.[324] The interstitial implantation of bare glass "seeds" became widely adopted; it was improved upon by Gioacchino Failla (1891–1961), who conceived the replacement of glass by capillary gold tubes that provided filtration of low energy gamma rays and gave birth to the "gold seeds," in use in greater or lesser degree to this day. Duane's interest in the development of radiumtherapy, his association with the Harvard Cancer Commission, and the lack of trained clini-

Fig. VI-6. Doctor of Philosophy Duane, associate of Pierre and Marie Curie, in Paris (1904).

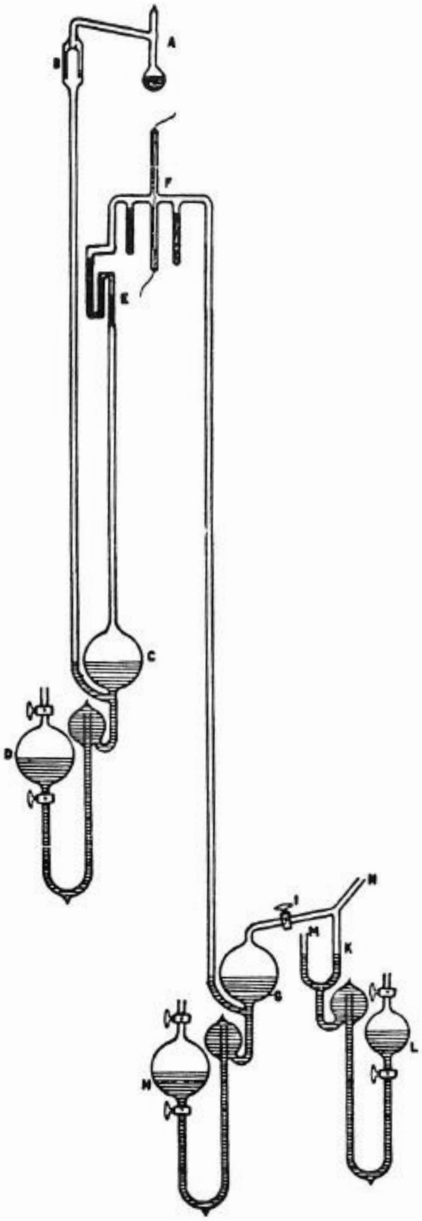

Fig. VI-7. Diagram of the radon extraction plant designed by Duane. The radon emanated by the solution of radium salt in *A* is brought by *B* by a mercury pump *C* and later pressed through *D* and relieved from impurities. Additional hydrostatic pumps form the radioactive gas into capillary tubes connected with *E*.

cians in the field brought him to prominence among oncologists of his time; he became an active member of the American Society of Cancer Research.

With the intensive work that he carried out during six weeks after his discovery, Röntgen had left little for others to add immediately. After a few year, William Henry Bragg (1862–1942) was among the first to advance a view (1904) of radiations with emphasis in *"quantal"* properties: that radiations are neutral pairs of α-particles and electrons. Charles Glover Barkla (1877–1944) discovered polarization (1905) and characteristic radiations (Nobel, 1917). Max von Laue (1879–1960) postulated that crystals are diffraction gratings for radiations (1912) by virtue of the regular arrangements of the atoms and molecules in lattic planes (Nobel, 1914). Shortly later (1912), William Lawrence Bragg (1890–1971), found diffraction governed by a simple relationship of the wavelength of radiations, the interplanar spacing of crystals, and the angle of incidence or angle of diffraction: *the Bragg law*[87] permitted the study of radiation spectra with known crystals or, conversely, the study of unknown crystal structures with radiations of known wavelength.[82]

In Boston Duane also gave attention to the study of the roentgen rays. John Trowbridge, his former teacher and predecessor, had left him a 45,000-volt storage battery that Duane perfected and augmented to 100,000 volts; the upkeep of his battery was both delicate and dangerous, as many of Duane's students discovered. The battery was an ideal power source to apply to the newly available hot-cathode tube and to precision spectroscopy.[82]

He also embarked on the newly developed study of radiation spectra; within one year of Bragg's original work, Duane developed an improved ionization spectrometer (1914) and through as many as five orders of reflection, made the first accurate evaluations of the wavelengths of the K and L series of tungsten.

With the assistance of Franklin Livingston Hunt (1881–1972), Duane found that constant potential did not necessarily produce a homogeneous beam of radiations. Duane defined the *effective wavelength* of a heterogeneous beam (its "center of gravity") as the wavelength of the monochromatic beam of radiations for which the reading of the measuring instrument would be reduced, in the same ratio as for the actual beam, when a sheet of absorbing material was placed in its path; Duane and Hunt found that the effective wavelength had a ratio within a factor of 2 of Planck's constant.[163] Quite naturally, Duane and Hunt set out to find the minimum wavelength in the heterogeneous beam; with precise methods that they developed, they were able to establish that there is a sharp upper limit to the frequency of radiations emitted by, and independent of, the target's material. They concluded that the product of the electromagnetic charge (e) and the accelerating potential (v) of a Coolidge tube is equal to the maximum energy ($h\nu_{\max}$) of the rays emitted by the tube. This rule, regarded as most accurate, came to be called the *Duane–Hunt Law*. Rutherford said of it: "There is, at present (1918), no physical explanation for this remarkable connection between energy and frequency.[26,351] Duane observed that, conversely, this equation could serve to find Planck's formula.[36] The Duane–Hunt law sometimes called the inverse photoelectric equation, became a factor of great importance in radiation spectroscopy, besides a measurement of Planck's action constant.

Karl Wilhelm Stenström (1891–1973),† a native of Gothenburg, Sweden, working for his Ph.D. at the University of Lund under Professor Karl Manne George Siegbahn (1886–1979), made original spectroscopic observations (1919) on the index of refraction of crystals and showed that these were actually slight departures from Bragg's law. Stenström interpreted the systematic *decrease in wavelength* as resulting from slight refraction of the incident radiations on the air–crystal interface. Professor Siegbahn (Nobel, 1924) reported his student's findings to the Paris Academy of Sci-

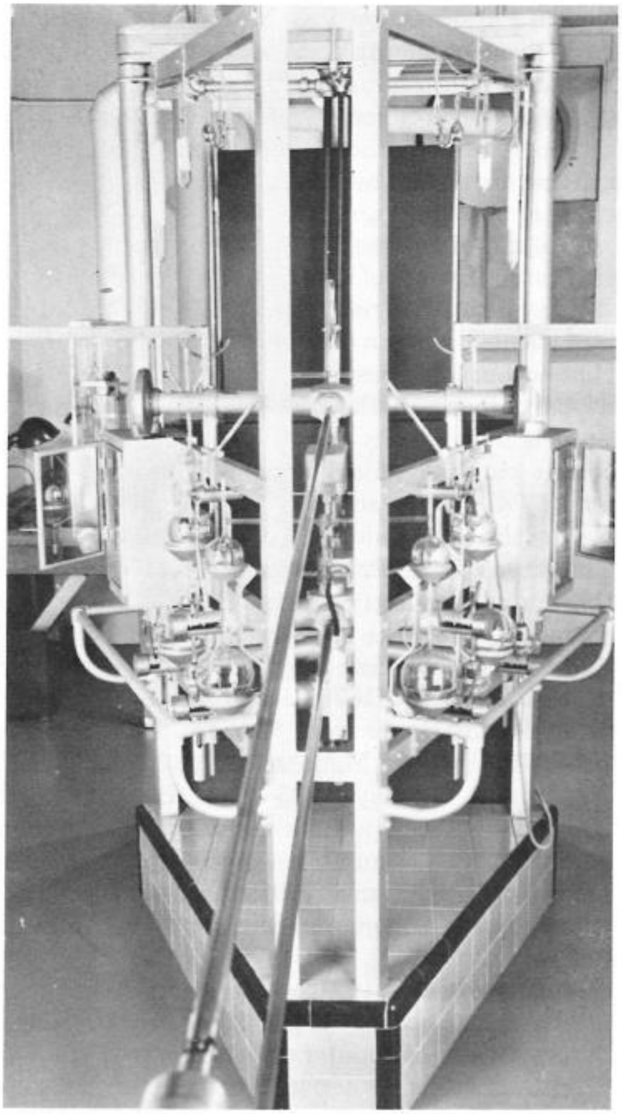

Fig. VI-8. Modern remotely controlled version of Duane's emanation extraction plant.

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† See Biographical Notes on page 171.

ences.[370] Duane and Kohert Alexander Patterson (1890–?), with the help of improved apparatus and good resolving power, studied the deviations from the Bragg formula and disregarded them, concluding that they were within experimental error.[166] Stenström came to the United States and joined Duane in his work at Harvard; they collaborated in spectroscopic studies of the *K* series of rays[168] and of the absorption of radiations by chemical elements of high atomic number. With his son, Arthur (1901–1928), Duane established that the intensity of scattered radiations decreases to zero as the angle of incidence decreases to zero. Barkla had announced his discovery (1916) of the *J* series of characteristic radiations, of shorter wavelength than the *K* series; Duane and Takeo Shimizu (1890–?) attempted to locate them in the emission spectrum, rather than in the absorption spectrum of aluminum[167] but found the evidence strong against their existence.
their existence.

In 1917 Duane was promoted to Professor of Biophysics at Harvard, indisputably the first such chair in the United States; he retained the title of Research Fellow in Physics under the Cancer Commission. The Duanes lived on Mount Vernon Street, then in Brookline, and on Massachusetts Avenue; they finally settled at 42 Beacon Street. Professor Duane sought relaxation from his numerous activities by playing the piano and organ and by joining his bridge partners at the Somerset Club (Fig. VI-9).

A report of the results of radiumtherapy during their first four years of work was published by Duane and Robert Battey Greenough (1871–1937); a total of 1080 patients had been treated by June 1917 with varied but encouraging results.[162] Duane was an enthusiastic participant in the meetings of the American Roentgen Ray Society to which he contributed his scholarly papers regularly; one of them received the *Leonard Prize* of the society,[159] and another was the subject of the third Caldwell Lecture.[160] He was one of the members of the Protection Committee appointed at the annual meeting (1920) in Curtis Hall, Minneapolis; it later became the American Roentgen Ray Society's Commission on Safety and Standards with Henry Khunrath Pancoast (1875–1939) as chairman. Other Commission members were William David Coolidge (1872–1975), Preston Manasseh Hickey (1865–1930), John Thomas Murphy (1885–1944), Bernard Henry Nichols (1876–1964), and James Lloyd Weatherwax (1884–1965). The Commission issued its first recommendations in September 1922. In September 1924 Duane was elected *Honorary Member* of the American Roentgen Ray Society.

In the summer of 1921, Madame Curie came to the United States to accept the gift of one gram of radium obtained through a popular collection throughout the country and given to her in the name of American women.[*] It is an often repeated anecdote that when asked by the president of the University of Chicago what did she wish to see in the United States, she responded: "Niagara Falls, the Grand Canyon, and Guillaume Duane." During her stay in Boston, Marie Curie and her daughters, Irène and Eve, were the Duanes' house guests at 6 Massachusetts Avenue. A formal ceremony of welcome to Mme. Curie was held at the Sanders Theatre in Cambridge, Massachusetts on June 20th, 1921. Radcliff, Wellesley, and Simons Colleges joined Harvard in its tribute.

One of Duane's graduate students, George Lindenberg Clark (1882–1969), was a chemist interested in crystallography.[94] Duane and Clark engaged in a study of crystal analysis with a modification of the Laue approach in which the maximum frequency of each spot of the Laue pattern was measured independently by an ionization method.[89] Using the wavelength of the reflected radiations at a given angle (utilizing the Duane–Hunt limit), they determine the interatomic distances in the reflecting crystals. With potassium iodide, they found intense reflected radiations with the characteristic wavelength of the anticathode but also with the wavelength of the *K* series of iodine: they concluded that it resulted from the diffraction of the characteristic radiations emitted by the crystal atoms. Since selective reflection of characteristic radiations of the crystal atoms "*does not appear to be explicabie...by the theory of interference of waves...,*" Duane correctly interpreted this as a diffraction by a crystal, as a collision of a light quantum with a grating.[161] The essential feature was a novel and fruitful point of view: the quantisized transfer of momentum from photon to crystal lattice; the frequency entering into the quantal relationship was found in the periodic repetition in space of the structure of the crystal. Duane's model, in which the periodic structure can change the component of momentum, was not based on relativistic theory, and it preceded (by six months) the proposed rule for linear momentum[259] of Louis Victor de Broglie (1892–1962) (Nobel, 1929).

The *Duane rule*, as it was widely referred to, aroused great interest from a variety of scientists, including Arnold Summerfeld (1868–1951) of the University of Munich and Niels Bohr (1885–1962) of the Institute of Theoretical Physics of Copenhagen. Both Sommerfeld and Bohr (Nobel, 1922) corresponded frequently with and visited Duane in 1923. "A curious consequence of the theorist's efforts to achieve a more general statement of Duane's reinterpretation of diffraction"—says Forman—"was to bring forward once again the representation of grating (or crystal) by a Fourier[†] series or integral."[209] Duane pointed out that this fact made it possible, in principle, to determine the distribution of electrons in the diffracting crystal,[373] putting the method into a convenient form suitable for calculation.[89] The method became an indispensable part of the analysis of complicated crystals. The idea "which is the basis of all subsequent analysis of the structure of biologically important molecules"—says Forman—"did not catch on until advanced again a few years later... ."[209]

William Duane

Fig. VI-9. Harvard Professor of Biophysics Duane in Boston (1917). Signature.

For years after it was first enunciated, Einstein's theory of light pulses flying through space seemed to violate what was known about interference of light.[169] Robert Andrews Millikan (1868–1953), brought up on the wave theory of light, spent ten years at the University of Chicago testing Einstein's photoelectric equation; contrary to his own expectations, Millikan (Nobel, 1923) found (1915) unambiguous confirmation of this operation.[282] Further confirmation of the theory of light quanta was to come eight years later (1923) from the work of another American physicist, Arthur Holly Compton (1892–1962), working at Washington University in St. Louis (Nobel, 1927).

Compton was holding a substantial position as engineer for Westinghouse when he was granted (1919) a modest fellowship of the National Research Council; at Compton's request, Sir Ernest Rutherford (Nobel, 1908) agreed to accommodate him for a year of research at the Cavendish Laboratories in Cambridge, England. Compton's previous work had been concerned with x-ray diffraction and reflection. At the Cavendish he engaged in the study of the scattering of γ-rays[114]; he attended the lectures of Professor J. J. Thomson but was influenced primarily by the genius and contagious enthusiasm of Rutherford. When he returned to the United States, he became the Wayman Crow Professor of Physics at Washington University in St. Louis, Missouri. Since he was comparatively isolated, the new position offered unusual freedom for his work: he utilized very sensitive instruments that he and his brother, Karl Taylor Compton (1887–1964), had invented, and refined some of the absorption techniques to deduce spectral information[26]; he began serious study of theoretical interpretations of the scattering of radiations.

Compton was impressed by the French report of Stenström's conclusions[370] and verified Stenström's prediction that if the wavelength is decreased, the index of refraction had to be less than unity. In the opinion of Samuel K. Allison (1900–1965), Compton's determination of the index of refraction of x-rays, said to be the first confirmation of Drude–Lorenz formula, would of itself rank him among first-line experimental physicists.[3] The Division of Physical Sciences of the National Research Council, of which Duane was chairman, added Compton to their membership and charged him with writing a report: "*Secondary radiations produced by X-rays and some of their applications to physical probems.*" As Duane and Shimizu had before him, Compton found strong evidence against the existence of Barkla's *J* series radiations. Compton's preconceptions were committed to classical electrodynamics and negatively disposed to Einstein's quantum hypothesis. In his report, he was led to appraise the relative merits of classical and quantum theories of radiation and in the process, achieved new insights. He also reported his own observations: "*Recent spectroscopic measurements by the writer show that secondary rays have shown a distinct change in wavelength.*" According to Compton, Duane objected to the inclusion of his "revolutionary conclusion" in the report, but it was retained through the insistence of another member of the committee.[209] As stated by Roger H. Steuwer,[383] Compton's view was revolutionary, his explanation was not, and his spectroscopic measurements could have been held inconclusive at the time.

In his discussion, Compton found classical theory irreconcilable with the view that secondary rays of greater wavelength than the primary rays may have their origin in the scattering process; however, he added that scattered energy is not necessarily radiated or absorbed in quanta, concluding "...it seems to me questionable whether the quantum interpretation of this experiment is the correct one." A few months after these vacillations, Compton was the first to work out a quantal equation predicting the change of wavelength in the scattered radiation and to report a phenomenon that others had observed but had been unable to rationalize,[26] that the wavelength of rays coming from a collision of a photon with an electron was larger than the wavelength of the rays that set up the action, what is known today as the *Compton Effect*.[116] The wavelength shift may be mathematically stated as a trigonometric (cosine) function of a scattering angle, utilizing two constants: the velocity of light and Planck's. Compton, now at the University of Chicago, reported his views (April 1923) to the American Physical Society.[234] Duane's honest role in the resulting controversy turned to his historical disadvantage.[26,384]

In 1923 Duane was president of the Society for Cancer Research; he had received the John Scott Medal from the city of Philadelphia and was elected to receive the Comstock Prize of the National Academy of Sciences for establishing "relations of fundamental significance...in their bearings upon modern theories of the structure of matter and on the mechanism of radiation." In this same year, he was given an honorary Doctor of Science degree by the University of Pennsylvania; an equally *honoris causa* distinction was offered by the University of Colorado. Duane was then considered the outstanding American radiation spectroscopist. At Harvard's Jefferson Laboratories, Duane's crystal spectrometer gave different results in the study of the scattering process than those observed by Compton. Duane interpreted the longer wavelength radiations as "tertiary" of the *bremsstrahlung* type.[96] "*I have no doubt*"—wrote Duane to Bohr—"*that the shift in the wavelength that A. H. Compton has been writing about should be abscribed to the tertiary radiation.*" Using 15 different substances as scatterers, Clark and Duane could identify every peak in their secondary spectra either as a tungsten peak or as a fluorescent peak ("tertiary hump").[97]

A debate was staged at the December 1923 meeting of the American Physical Society in Cincinnati. Compton presented his spectroscopic data and added that Wilson's cloud chamber provided direct evidence; he quoted Sommerfeld as stating that Compton's discovery "sounded the death knell of the wave theory." He declared to have been converted to the view that radiations consist of directed quanta and stated that the only glimmer of hope for a reconciliation of the wave and particle theories was "the trail blazed by Duane in his quantum derivation of Bragg's law.[161]

In Cincinnati Duane opposed Compton's theory of scattering. In the early part of 1924, Duane visited the Ryerson Laboratories and had a first-hand opportunity to observe Compton's work; it was Duane's view that the findings resulted from a "box effect" because of the circumstances of the experiments. Compton went to Boston as Duane's house guest and was unsuccessful in demonstrating the Compton Effect at Harvard.[4] "*Professor Compton himself was here and helped to perform some of the experiments*"—wrote Duane to Sommerfeld. "*He said that he was unable to explain the (Harvard) results...* ." At the 1924 summer meeting of the British Association for the Advancement of Science in Toronto, another debate between these two antagonists was presented under the chairmanship of Sir William Bragg (1862–1942). Impartial observers found their respective presentations equally convincing.

A spirited reporter for *Nature* wrote: "In an exceptionally successful session...no discussion created such widespread interest as that which centered around the papers of Prof. Compton of Chicago and Prof. Duane of Harvard on the scattering of X-rays...each...appeared to have almost overwhelming evidence in favour of his point of view, and had the audience only listened to one side—either side would have done equally well—it would probably have been convinced as to the accuracy and soundness of the views advanced." He went further to quote from the Beggar's Opera:

"How happy could I be with either
Were t'other dear charmer away!"[17]

Compton himself called the debate a draw. He related that he had been approached by Chandrasekhara Venkata Raman (1888–1970), the distinguished physicist from Calcutta (Nobel, 1930), who told him "Compton, you are a very good debater, but the truth isn't in you."

The difference eventually was dispelled by Duane in his laboratories. In the honest and respectful interchange, Duane found defects in the circumstances of his own experiments, a combination of fortuitous coincidence and experimental error: his beam was too broad, there were spurious effects resulting from impurities in the composition of the target of his x-ray tube, and there was also scatter from parts of the equipment. Duane and Allison carried out the most accurate measurements yet of the Compton shift.[6] "*I am perfectly delighted to be able to write to you*"—said Duane to Compton—"*that we have recently obtained what appears to be perfectly definite evidence for scattered radiations with shifted wavelengths corresponding substantially with your interesting theory.*"

At the annual meeting of the Physical Society held during the 1924 Christmas season in Washington, D.C., Duane made what witnesses considered an admirable as well as forthright admission of his error ("... a pleasant memory to all who heard it"[89]). Unfortunately, the short published proceedings of the society deprives us the enjoyment of the high ethical spirit of the occasion. Thus an unfortunate yet fruitful controversy ended. Third parties are often more belligerent than the contenders; also, in their passion to identify with the winner, they may fail to appreciate the qualities of the loser.[209] In the aftermath of this affair, there were left a few spectroscopic questions agreed upon by Compton[89] *; there was also the validity of Duane's quantal rule and his credit and precedence in the matter of linear momentum.[63,161,259] Duane and Allison verified with much greater precision de Broglie's conclusion that the characteristic frequency of any substance is the same, whether excited by electrons or x rays.[9]

Duane had an early interest in ionization chambers; already in 1905 he had pointed at the wall-effect, which did not permit the use of small chambers for dosimetry. In 1914 he reported to the American Roentgen Ray Society on this approach to the measuring of quantity and quality of radiations,[156,158] and he defined his unit of intensity (the electrostatic unit-second) as that which *produces under saturation conditions one electrostatic unit of current per cubic centimeter.* There is little doubt that Duane's was one of the earliest ionization chambers built in the United States; the size of the chamber, which had to be increased to satisfy the requirements at higher voltages, was gradually reduced (from 200 to $10\ \mathrm{cm}^3$) as better galvanometers were built.[165] With Egon Lorenz (1928), he published the details of a standard ioniza-

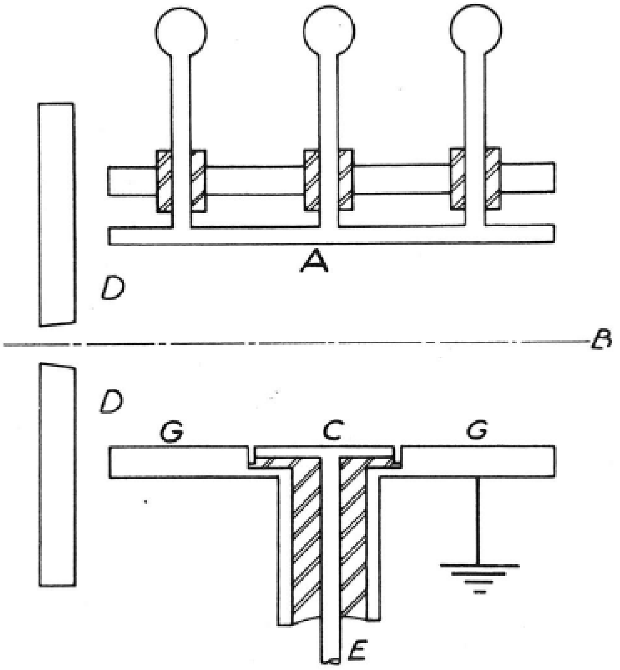

Fig. VI-10. Duane's standard open-air ionization chamber consisting of two parallel plates, one of which *A* may be moved to any desired distance from the other; an insulated portion of the opposite plate *B* is connected to a galvanometer *C* that measures the ionization current.

Fig. VI-11. Professor Emeritus Duane (1934).

tion chamber (Fig. VI-10), variations have been introduced but no fundamental changes in Duane's original method. In Europe other chambers were produced and other units proposed; there was a French unit, called Roentgen, and also a German Roentgen. At the Second International Congress of Radiology, held in Stockholm in 1928, an *International Unit* was adopted; it was called a *roentgen* and represented by a lower case *r* to differentiate it from the *R* units already in use. The adopted definition was the one Duane had used since 1914, slightly modified as it had been in the German unit.[28]

A variety of other contributions and "firsts" are credited to Duane by Clark,[95] among them: the first study of general ("white") radiation and the correlation of intensity with the atomic number of the target element; the first therapeutic use of thorium and uranium as targets; the first measurements of radiation spectra from aluminium targets; the study of the radiation spectrum of an extremely thin target (stream of mercury) and the demonstration that an almost monochromatic spectrum is produced. Clark also credited Duane with the discovery of characteristic emission lines resulting from conductivity electrons falling into the *K* energy level in the atom and with proof of identity of the value of characteristic ionization of characteristic absorption and of quantal wavelengths.

Despite the progress made in a relatively short number of years, the difference between the classical electrodynamic concept of radiations as *waves* and their quantal conception as *particles* had not been resolved: Bragg (1927) suggested that physicists use one or the other concept on alternate working days of the week; presumably, Sunday's would fall under loftier guidance! The relativity theory does give the constituents of matter an intrinsically dynamic character, but the relativistic identity of mass and energy as well as of space and time are dificult to integrate into every concept. In recent years, Alfred Landé (1888–1975)† offered a new foundation for the quantum theory, outflanking wave–particle dualism. Without entering into the controversial intricacies of this farrago,[63,258,260] it is only pertinent here to point out that it has brought to light again Duane's formulation of the momentum rule for the explanation of refraction of radiations in crystals, using the corpuscular theory of light without relativistic theory. According to Lande,[254] the dualistic interpretation began after the experiment of electron diffraction appeared to allow no other interpretation but that particles of matter pass through wave interludes near a screen or screen with slits; he believed that the unphysical transmutation could have been avoided if quantum physicists had been aware of Duane's quantum rule for linear momentum. Duane's rule (March 1923) describes correctly all experiments of momentum exchange on periodic structures. Max Born (1882–1970) (Nobel, 1954) commented that in de Broglie's work (September 1923), Planck's and Duane's rules are recognizable and interconnected.[63]

In 1925 the Regents of the University of Colorado accepted from Dr. and Mrs. Duane the gift of eight acres of land on Arapahoe and 24th Street in Boulder, Colorado; the land was used first for football practice and subsequently became the site of Newton Court, housing for married students. Duane took his first sabbatical in 1926 after thirteen years at Harvard. He attended the Volta Congress of Physics at Lake Como, Italy in 1927. In 1928 he was active as a member of the important Committee on Standards at the Second International Congress of Radiology in Stockholm.

In his sober search for intellectual integrity, Duane had to contend with impaired health: he suffered from diabetes and as a consequence, lost the acuity of his sight. His wholeness of mind and heart was further imbalanced by the premature death of his second son that added unconscionably to his grief. Duane suffered a paralytic stroke from which he recovered only partially. The last three reports of his work to the National Academy of Sciences were presented in 1932. In 1934 he resigned and was appointed Harvard Professor Emeritus of Biophysics (Fig.VI-11). On 7 May 1935 William Duane died in his home at Devon, Pennsylvania.

Because of the persistently devoted efforts of Professor A. A. Bartlett, a proposal that first was ad-

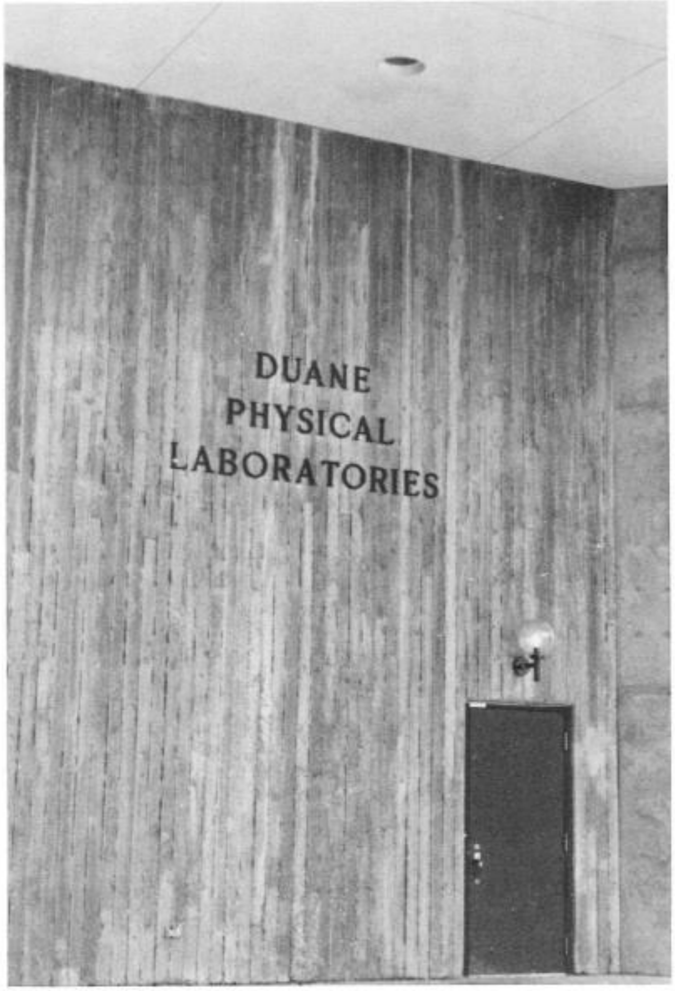

Fig. VI-12. Entrance to the Duane Physical Laboratories, University of Colorado, Boulder, Colorado.

Fig. VI-13. The Duane Physical Laboratories of Boulder, Colorado, including the tower in honor of George Gamow (1904–1968) and the auditoria in honor of Frank C. Walz (1899–1971).[27,28]

vanced in 1951 became a reality in 1972 with the formal dedication of the Duane Physical Laboratories of the University of Colorado; they include the Frank C. Walz Lecture Halls, a novel concept of auditoria,[7] and the George Gamow Tower: a just memorial to the finest of teachers (Figs. VI-12 and VI-13).

Duane's older son, William Duane, Jr. (1900–1962), was a 1927 graduate of the University of Pennsylvania, became a neurosurgeon and served in the U. S. Army Medical Corps in the Second World War. Arthur Ravenel Duane (1901–1928) had brilliant beginnings as a scientist; during a visit to her home, Mme. Curie noticed signs of anxiety in the young man ("il était inquiet...il est parti sans lesser d'addresse"). He had become mentally ill and died prematurely under strange circumstances. Prioleau Duane (1909–1967) changed his first name officially to John in North Carolina. Margaretta Clarissa Duane, Mrs. Richard D. Wood, is the only surviving child; she revels in the memory of her father and brilliant brothers in Hurricane Hall in Wawa, Pennsylvania.

A number of Dr. Duane's former associates and students attest to his modesty of character; many remember him as an exemplary model of a scientist, yet artistic sensibilities shared in his personality. His sense of professional ethics was of the highest. He was a very reserved, soft-spoken man, and was difficult to know intimately; most of those who worked near him saw him only distantly but genuinely admired him. One of his associates described him as quiet, kindly, modest and considerate, personifying the ideal combination of man of science, tender father, teacher and delectable friend.[14] He was endlessly creative, and his greatest joy was working with students; his influence radiated, not through his words, which were few, but through inspiring a life of work as he was capable of. Percy William Bridgman (1882–1961) (Nobel, 1946) remembered Duane's persistence of purpose and his winsomeness of spirit.[12] A remarkable number of graduate students, some twenty by our own count, did work and appeared as co-authors of a variety of Duane's publications.*

Duane's original pursuits and genial concepts in nuclear physics eventually became the springboard of new ideas or an integral part of recognized contributions by others. Except for the Duane–Hunt law, his works failed to attract wide and simultaneous recognition. In the historical perspective, his works place him in a position of exceptional leadership.

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* See Subject Notes on page 183.