The discovery of synchrotron radiation

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Thirty-five years ago the electromagnetic radiation that results from the acceleration of electrons in a circular accelerator was observed for the first time in a 70-MeV synchrotron at the General Electric Research Laboratory in Schenectady, NY. In May 1981, an entire issue of *Physics Today* was devoted to synchrotron radiation, which is widely recognized as an important research tool for physicists, chemists, and biologists and perhaps in medicine as higher-energy synchrotrons and electron storage rings have been constructed. It seems timely to review the background of its discovery at this laboratory and to record the exact circumstances of the first visual observation and measurements of the radiation.

Before discussing the first observation of synchrotron radiation from a laboratory machine it should be noted that for centuries man had been seeing synchrotron radiation from stars or galaxies without knowing that some of their light resulted from the acceleration of elementary particles in the large magnetic fields associated with astronomical objects.

In 1898 Liénard[1] first pointed out that an electric charge moving in a circular path should radiate energy and he calculated the rate of radiation from the centripetal acceleration of an electron. The theory was extended subsequently by Schott,[2] who received the Adams Prize in 1908 at Cambridge University for his essay, "The Radiation from Electric Systems or Ions in Accelerated Motion and the Mechanical Reactions on their Motion which Arise from It." Schott, attempting to provide the background for an electron theory of matter, calculated the amount and the angular distribution of radiation from relativistic electrons grouped in various ways in orbits of proposed atomic models.

Three decades later, when the building of multimillion volt accelerators began, the classical radiation loss of accelerated electrons again received attention. Circular electron accelerators of various designs were proposed, by Slepian (1922) at Westinghouse, by Wideroe (1928) in Norway, and by Kerst and Serber[3] (1941) at the University of Illinois. The first such machine which was successful was the 2.3-MeV betatron which Kerst built at Illinois. In this machine radiation loss from the electrons was so small that it could be neglected. With the building of larger electron accelerators the increase of radiation loss, as the fourth power of energy for relativistic electrons, became a serious matter. Two Russians, Ivanenko and Pomeranchuk,[4] pointed out in a letter to the *Physical Review* in 1944 that radiation loss would indeed place an energy limit on betatron design.

At the time William D. Coolidge, the eminent x-ray-tube pioneer and inventor of ductile tungsten, who was the Director of this laboratory, had initiated the construction of a 100-MeV betatron in Schenectady. This large induction accelerator for x-ray and nuclear research was designed by Westendorp and Charlton.[5] A GE physicist, J. P. Blewett, who had seen the Russians' paper, urged that an experimental test be made of their predictions. When the machine came into operation Blewett,[6] believing that a total radiation power of about 1 W might be available for detection, searched the radio spectrum from 50 to 1000 megacycles with receivers capable of detecting less than 10 μW. No radiation was detected. It was known that near the peak energy in the betatron the beam orbit began to shrink and the electrons impinged on a target inside their stable orbit. Blewett showed the orbit contraction was consistent with the radiation loss predicted by Ivanenko and Pomeranchuk. He also showed that the deflection current in orbit contraction coils on the machine pole faces was consistent with an orbit size reduced by classical radiation. At about this time Schwinger[7] of Harvard worked out in great detail the theory of the classical radiation of accelerated electrons. The calculations, made available to Blewett and others, but not published until 1949, made it clear that the radiated energy would not peak in the low harmonics of the orbit frequency where Blewett had searched but in the near infrared or in the visible spectrum. If the 100-MeV betatron had been built with a transparent glass vacuum tube, as was a 70-MeV synchrotron in 1946, synchrotron radiation today would be called betatron radiation.

Why was a 70-MeV synchrotron built in 1946 in a laboratory which already had a 100-MeV betatron in successful operation? Several GE physicists and engineers had been assigned by Coolidge in 1943 to work at Berkeley on the Manhattan Project research directed by Ernest O. Lawrence. After the war, in late 1945, Lawrence made one of his frequent Schenectady visits and at a seminar with these physicists and others discussed the principle of synchrotron acceleration, recently proposed by McMillan[8] at Berkeley. McMillan and Lawrence were beginning to plan construction of a 300-MeV synchrotron for nuclear research. The magnetic guide field of a synchrotron would be similar to that of a betatron but the electrons would be accelerated by rf voltage between dees, or in cavity resonators, rather than by magnetic induction. McMillan believed the electrons would accept energy from the rf system so as to maintain a stable orbit, its size defined by the frequency, and he also thought the synchrotron phase stability principle would compensate for classical radiation losses. During a brief discussion of ways to inject electrons into the proposed machine, Pollock[9] suggested to Lawrence that induction acceleration up to 2 MeV in each magnetic cycle could bring the electron velocity to approximately 98% that of light, at which time in the cycle a fixed frequency oscillator might bunch the beam and continue the acceleration. After the seminar Willem Westendorp and Pollock explored further the possibility of testing McMillan's synchrotron invention and the betatron injection idea. By modifying the design of a 50-MeV dc-biased betatron magnet which Westendorp had already developed for the GE X-Ray Company (then interested in high-voltage x-ray therapy), it appeared one could make an early test of several ideas and see if any unsuspected obstacles were present.

With the support of Coolidge and C. G. Suits, who had then become Director of Research, Pollock was allowed to bring together a team to build a 70-MeV synchrotron.[10] An 8-ton ac magnet, with a pole face 27 in. in diameter and a $2\frac{1}{2}$-in. gap for the circular glass "donut," provided the magnetic guide field for the new synchrotron. Frank Elder worked on the design of the power circuit and the laminated magnet, which was assembled by machinist Floyd Haber. Anatole Gurewitsch focussed on the 163-Mc rf cavity resonator design and Phil Noble on the circuits to drive it. Robert Langmuir and Pollock put the various components together and on 24 October 1946 we were able to tell Edwin McMillan in Berkeley that we had a synchrotron beam and that no problem had been encountered in bunching 2 MeV betatron current for synchrotron acceleration to 70 MeV. Soon after successful operation a magnet coil failed. There followed weeks of delay while we awaited new coils, and while we improved electron guns, rf resonators, and other equipment. By spring the 70-MeV synchrotron was able to operate with much better components. The optical radiation from the electron beam was first seen on 24 April 1947—unfortunately somewhat later than we might have seen it. (See Fig. 1.)

On that April day Langmuir and Pollock were running the machine and as usual were trying to push the electron gun and its associated pulse transformer to the limit. Some intermittent sparking had occurred, and Haber was asked

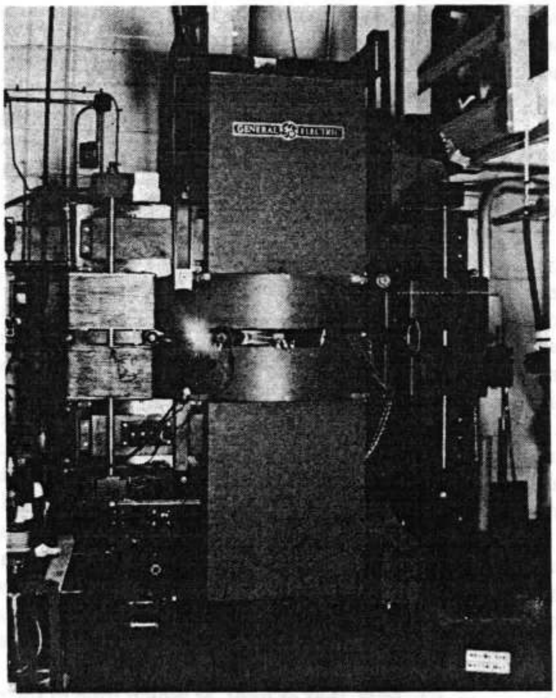

Fig. 1. 70-MeV synchrotron with optical radiation from the electron beam visible through the glass wall of the vacuum "donut" tangent to the beam orbit.

to observe with a mirror around the protective concrete wall which separated the machine from the control room. He signaled to turn off the synchrotron as "he saw an arc in the tube." The vacuum was still excellent so Langmuir came to the end of the wall and observed. Pollock's notebook record for that date reads as follows:

We had some sparking from one of the pulse transformers. When Haber looked around the corner of the wall he noticed a very bright spot of light coming from the tube on the left hand side. This light only appeared when the rf was running and the timing of the gun was right. At first we thought it might be due to Cerenkov radiation but it soon became clear that we were seeing Ivanenko and Pomeranchuk radiation. For the intensity remained high when we decelerated the electron beam from 70 MeV to 10 MeV without bringing the beam to the target or gun. We observed the bright spot with mirrors, looking tangent to the orbit at two or three points in the room. The intensity decreased as the peak energy was reduced. When the energy was of the order of 20 MeV it was no longer visible. We showed the effect to Dr. Charlton, Dr. Kingdon and various others. The beam appeared stable and of small cross section (perhaps 1 mm square).

A recent letter from Robert Langmuir, now Emeritus Professor of Electrical Engineering at the California Institute of Technology, gives his recollection of the event: "I have very definite and clear remembrances about the discovery of synchrotron radiation. I don't remember the date (presumably 24 April 1947) but in the afternoon one of the technicians reported to me that there seemed to be sparkling in the synchrotron tube. He observed this by looking in the large (about 6 ft high by 3 ft wide) mirror that permitted us to observe the machine without getting too much radiation. You were at the controls of the machine. Upon seeing the light, I asked you to ruin the timing, which you did and the light went away. It returned when you returned the injection pulse to the proper time. I immediately said that must be Schwinger radiation. The whole incident took about thirty seconds. We then changed the energy of the beam and noticed that the blue–white color at 70 MeV became yellow at about 40 MeV. I don't remember whether we had good shades on the windows at that time, but then or later we could see the beam become red (and quite weak) at about 30 MeV."

Langmuir continues: "In view of the above, the light was first seen by the technician—I don't remember his name. He thought it was sparking. I, and almost immediately thereafter you, recognized it to be what I called at the time, 'Schwinger radiation.' Just who gets the credit for discovering the light is not clear. What is clear is that you and I knew what it was and the technician didn't. I see no reason why the technician should get any scientific credit—just credit for keeping his eyes open."

For 25 years the late Floyd Haber got that credit at the laboratory, for having eye-balled synchrotron radiation ahead of all those scientists who might have seen it sooner. His alertness was once praised in *Physics Today* by George Baldwin,[11] who also pointed out he might well have made the observation with the betatron in 1944.

In 1974 there occurred a curious event which has made me grateful for having been in this laboratory when its first director, Willis R. Whitney, still actively gave advice to each scientist. Whitney used to emphasize the importance of written notebook records, witnessed from time to time by a colleague. He would say, "Write in your notebook every day even if you have to write that you didn't do a damn thing. It makes you know what you've done and what you should do next." In November of 1974 A. M. Bueche received from a technician who had left the Company in 1949 a 12-page sworn affidavit claiming that at 1:15 PM (EDST) on 31 July 1948 he, Gerald Knowlton, rather than Floyd Haber, had been the first person to observe synchrotron radiation. He alleged that a nonrecognition of this by the scientists had damaged his reputation and he suggested, with various allusions to atomic bomb research, that his health may have been damaged. A GE reply to Knowlton's affidavit pointed out that his claim alleged a date of discovery 15 months after the event had been described in Pollock's notebook and 14 months after it had been reported to the *Physical Review* on 9 May 1947 by Elder *et al.*[12] who had made all measurements and analysis of the radiation from the machine. The company furnished Xerox copies of all relevant pages from notebooks of those who were involved in the 1947 work. The one and only reference to synchrotron radiation in Knowlton's own notebook, preserved in the library files, was on 9 May 1947 where he stated there was "much excitement around on account of 'visible' radiation losses." He had also inserted in what he agreed was his own writing, "First observed Apr. 24, 1947 by Floyd Haber." However, Knowlton did not withdraw his claim but simply revised his affidavits to correct the chronology and to make allegations which were inconsistent with the written records of the time and the recollections of others. For three years Knowlton continued to press his claim with letters and affidavits to the Vice President (usually with copies to the American Institute of Physics). As a result of his campaign some articles now mention Knowlton as the discoverer of synchrotron radiation.

It has been said the light was but a scientific curiosity[13] at first. That is not entirely correct. It was of immediate use in optimizing synchrotron adjustment, operation, and design. Three 70–80 MeV machines were built for other institutions and larger synchrotrons were planned with more confidence as to their electrical and mechanical specifications. The spectrum of the light from the 70-MeV synchrotron did not extend into the ultraviolet and x-ray regions but the GE work[14] and that of Hartman and Tomboulian[15] with the 300-MeV Cornell synchrotron, established experimentally the properties of this intense, polarized, and highly directional source of radiation.

There was indeed curiosity about the light from electrons. Within a month of the first observation Suits had brought the President of the Company, Charles E. Wilson, and the entire Board of Directors to see the light. Only Suits can say if this may have helped in his effort to obtain funds for the new Research and Development Center. There were many other things to show directors and of more commercial importance. From the academic community there were many visitors between 1947 and 1949. Among them we can count six Nobel prize winners. With other visitors came Klaus Fuchs, the famous Russian spy, clearly capable since none of us in the synchrotron room could remember his visit until it was documented beyond question by the FBI. Another visitor for 20 minutes was Ronald Reagan, being given an overall view of GE research. Perhaps it is now time to remind Mr. Reagan that 35 years ago he was one of the first to see synchrotron radiation which today is an important scientific tool in several of the national laboratories.

[1]A. Liénard, L'Eclairage Elec. **16**, 5 (1898).
[2]G. A. Schott, Philos. Mag. **13**, 189 (1907); *Electromagnetic Radiation* (Cambridge University, Cambridge, 1912).
[3]D. W. Kerst and R. Serber, Phys. Rev. **60**, 53 (1941).
[4]D. Ivanenko and I. Pomeranchuk, Phys. Rev. **65**, 343 (1944).
[5]W. F. Westendorp and E. E. Charlton, J. Appl. Phys. **16**, 581 (1945).
[6]J. P. Blewett, Phys. Rev. **69**, 87 (1946).
[7]J. Schwinger, Phys. Rev. **70**, 798 (1946); **75**, 1912 (1949).
[8]E. M. McMillan, Phys. Rev. **68**, 143 (1945).
[9]H. C. Pollock, Phys. Rev. **69**, 125 (1946).
[10]F. R. Elder, A. M. Gurewitsch, R. V. Langmuir, and H. C. Pollock, J. Appl. Phys. **18**, 810 (1947).
[11]G. C. Baldwin, Phys. Today **28**, 9 (1975).
[12]F. R. Elder, A. M. Gurewitsch, R. V. Langmuir, and H. C. Pollock, Phys. Rev. **71**, 829 (1947).
[13]M. L. Perlman, E. M. Rowe, and R. E. Wilson, Phys. Today **27**, 30 (1974).
[14]F. R. Elder, R. V. Langmuir, and H. C. Pollock, Phys. Rev. **74**, 52 (1948).
[15]D. H. Tomboulian and P. L. Hartman, Phys. Rev. **102**, 1423 (1956).