

## Chapter 7 Case Experiment Takes Off

**Olsen, Crittenden, Shrader, Gregg, Smith, Scharenberg, Silverstein**  
 37-60    38-56    40-69    45-61    42-68    61-65    64-69

In 1935 the Case department consisted of Miller, Albright, Nusbaum, Hodgman, Wallace and Shankland. Only Shankland was doing work that could be described as “modern” experimental physics. By 1945, the department had added five young experimentalists: **Olsen, Crittenden, Shrader, Gregg and Smith**. A full research program had come into being, and the directions to be taken by physics research at Case were beginning to be defined. **Fig. 7-1** is a photograph of the members of the department in 1945.

### Research costs money

While both Case and Western Reserve had modest research programs in technology and the sciences from their beginnings, things really started to take off during and after World War 2. This was true of course at all American research universities. Both



**Fig. 7-1.** seated: Crittenden, Smith, Shankland, Shrader, Gregg.

industry and the government took advantage of the concentration of knowledgeable faculty and they were willing to pay for it. The universities were happy to accept large sums in overhead charges which they would invest in expanding their faculties and facilities.

The chemistry departments of both Case and WRU and the engineering departments at Case had established relationships with corporations such as Dow Chemical, General Electric, Sherwin Williams, Lubrizol and Standard Oil. The physics departments

had rather modest industrial funding before 1942. Their research was in general too “basic” for commercial applications. The war changed this. Industry and government came to the physics community asking for help in electronics for communications and radar, in sonar, optics, materials and basic atomic and nuclear physics.

The research programs of the two physics departments would be funded almost exclusively by the Department of Defense, the Atomic Energy Commission, and later by NASA and the National Science Foundation. The critical role of science in determining the outcome of the war would open the minds and purses of the federal government, even for the rather basic research pursued by the CIT and WRU physicists. The resulting in-

creases in funding would allow the expansion of each department from 5-6 in the 1930's to 25-30 in the 1960's.

Darwin H. Stapleton, former professor in the CWRU department of history, discusses the funding situation at CIT and WRU and some of the problems it entailed in a 1993 paper. "The Faustian Dilemmas of Funded Research at Case Institute and Western Reserve, 1945-1965". *Sci. Tech. & Human Values* **18** 303 1993. His main point is that, while the money was welcome, the control of the research (and associated teaching) would be taken out of the hands of the faculty, in violation of the nationally accepted standards of academic freedom and faculty governance. Most of the faculty and many in the administration were uncomfortable with the pursuit on campus of classified defense research.

As an example of classified work, Stapleton describes a program which accounted for half the CIT federal funding between 1951 and 1958. The "Doan Brook Project" involved scientists, engineers, and social scientists, had a staff of over eighty, and supported about 40 grad students. This "systems analysis" research dealt with aerial seeding of antitank and antipersonnel mines. In 1962, Case's Faculty Committee on Research declared that the publication of research done on campus should not be restricted. Classified projects would no longer be undertaken.

Another important impact of the quest for external funding from government, industry, and even from charitable foundations, was considerable pressure on the two institutions to federate. The inevitable union took place on 1 July 1967. I quote an entire paragraph from Prof. Stapleton's paper because it so much relates to our story.

"The initial years of federation were difficult ones, especially for the science departments. Resistance by Case alumni to the fund-raising effort called for by the Heald Commission (author's note: this was the outside advisory group which recommended federation) exacerbated the effect of the general decline in federal funds in the latter 1960's. Moreover, there were serious problems with faculty morale as the administration pressed for unified departments of physics and mathematics in addition to chemistry and had to overcome delaying tactics and in some instances outright refusals to cooperate with the federation process. Faculty found that the merged departments were expected to be smaller and many left in anticipation of a future termination. It was an agonizing period for much of the university community."

### **Olsen and the GE connection**

We return to the Case physics research story and the new practitioners. **Leonard O. Olsen**, with a PhD from the University of Iowa, was hired in 1937. He studied the interaction between light waves and the atoms of rare gases. This work led to a connection between the department and the General Electric Company's Cleveland-based lighting research group at Nela Park (acronym for National Electric Lamp Association), a connection which was to flourish for at least four decades. In two 1941 papers, Olsen and Iowa colleagues present theoretical and experimental results on the quenching and

depolarization of ultraviolet light (the 2537 Å mercury line) in He, Ne, Ar and Kr gases as a function of pressure and applied magnetic field. Olsen would return to this research after the war, publishing a paper based on work done with his MS student, George Kerr. Kerr later joined the research group at General Electric. This work was similar to that done in 1941, but this time nitrogen and oxygen were studied. An expanded experiment involving eleven different gases was published in 1960. The techniques were brought up to date with the use of photomultiplier tubes as detectors, and with the data analysis done on the department's new state-of-the-art IBM 610 computer. "Collision Processes in Mixtures of Mercury Vapor and Foreign Gases" *Phys. Rev.* **119** 691 1960.

Toward the beginning of World War II Olsen and several colleagues at Case put together a crash program to train students in acoustics, in an effort to provide new manpower for war-related research. In 1942, thirty-two students from Case, from industry, and from nearby liberal arts colleges participated in a program which introduced them to electro-acoustics and supersonics. Among the instructors in the program was MA student Earle Gregg (to be introduced shortly) who discussed piezoelectric and magnetostrictive transducers. Most of the students went on to such places as the labs of MIT or directly into military research groups. ("Training Men in Acoustics and Supersonics for War Research" *Amer. J. Phys.* **10** 262 1942.) With Shankland's (Chapter 6) and Foldy's (Chapter 9) wartime research in New York and this related training effort back in Cleveland, Case contributed valuable expertise in acoustics to the war effort.

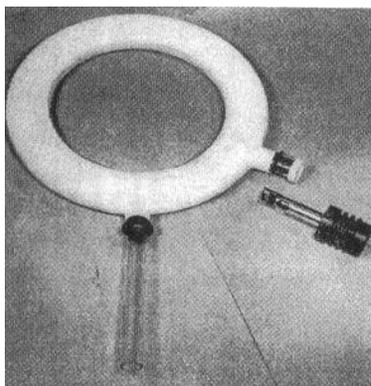
### **Crittenden and plans for the Case betatron**

**Eugene C. Crittenden, Jr.**, hired in 1938, had published two papers on beta decay in connection with his doctoral research at Cornell. These concerned cloud chamber studies of beta-ray spectra of radioactive nuclei formed at the Cornell cyclotron. His early publications at Case include a paper on a teaching-lab experiment on forced damped oscillations (*Amer. J. Phys.* **17** 282 1943); a paper on the uniformity of low magnetic fields produced by Helmholtz coils (*Rev. Sci. Instr.* **15** 270 1944); and a paper on an electronic flow-meter designed for biological applications (*Rev. Sci. Instr.* **15** 343 1944).

In 1946, Crittenden spent time at the Radiation Laboratory at Berkeley where he studied the theory and operation of particle accelerators. This was at about the same time his later colleague, Leslie Foldy, was at the "Rad Lab", as we shall describe in Chapter 9. Crittenden wrote two papers for the *Journal of Applied Physics*, one on "Methods for Betatron or Synchrotron Beam Removal", the other on "A Graphical Method for Determining Particle Trajectories". (*J. Appl. Phys.* **17** 444 and 447 1946) He remarks that until that time, betatrons were used to create beams of X-rays produced when the internal electron beam hits a target. Since the electrons themselves were not extracted from the machine, Crittenden's studies on the production of beams of electrons would help to open up a new era in accelerator experiments.

Both Crittenden and Foldy subsequently played a role in the design of the betatron to be built at Case. This machine, with radius about two meters and a seven ton

electromagnet, was designed to produce a beam of 25 MeV electrons. The proposal presented to the Atomic Energy Commission stated that the research done with the betatron would include the study of fundamental particles at energies available only in cosmic rays, the study of nuclear structure, the production of radioactive isotopes and industrial X-ray radiography. The design called for a toroidal ceramic vacuum chamber placed between the pole pieces of the magnet. **Fig. 7-2.** An alternating current of order 100 Amperes with frequency 180 Hz would energize the electro-



**Fig. 7-2.** Ceramic vacuum chamber for betatron.

magnet. During the half-cycle when the magnetic field was rising, the induced electric field would accelerate the electrons. During that one 360th of a second, the electrons would reach almost the speed of light as they spiraled outward toward the edge of the vacuum chamber. At this point, the device, described in a 1950 paper by Crittenden and grad student Sherwood Fawcett, (*Rev. Sci. Instr.* **21** 935 1950) would superpose a 20 microsecond bump in the magnetic field which would nudge the electron beam out through the glass wall of the machine. The cost for the "Case Betatron" and its basement housing was estimated at \$39,000 (~\$300,000 in 2005 dollars). We shall return to Crittenden later, when he becomes interested in thin metallic films.

### Shrader, Gregg and the betatron

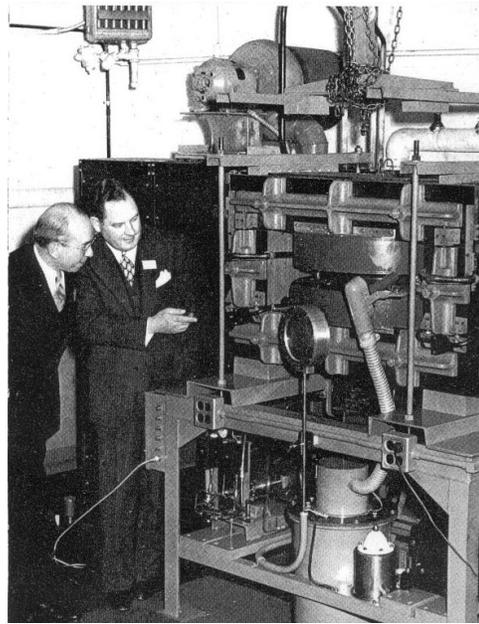
**Erwin F. Shrader** joined the department in 1940, a year before receiving his PhD from Yale. That year, he sent a short letter to the *Physical Review* describing his determination of the nuclear spin of the isotope  $^{37}\text{Cl}$  (*Phys. Rev.* **58** 475 1940). He had used thermal diffusion of HCl gas to obtain a sample of chlorine enriched in the  $^{37}\text{Cl}$  isotope. By measuring the absorption spectrum of this sample, and specifically the intensity ratios of several lines in the vibrational spectrum, he concluded that the spin of  $^{37}\text{Cl}$  is  $5/2$ , the same as that of  $^{35}\text{Cl}$ . For our story, it is interesting that Polycarp Kusch at Columbia took note of the young Shrader's work, and soon published a letter with him (*Phys. Rev.* **58** 925 1940). Kusch worked with molecular beams and used Shrader's  $^{37}\text{Cl}$  spin to extract the magnetic moment of that nucleus. Kusch (a 1955 Nobel prize winner) had done his undergraduate work at Case (BS 1931), and it is conceivable that he put the Yale student in contact with Case.

**Earle C. Gregg** earned a Case MS under Crittenden in 1942, joined the faculty in 1945, and completed his PhD with Erwin Shrader and Shankland in 1949. Gregg and Shrader would devote five years to building and testing the betatron. As early as 1946 Gregg wrote short papers on devices to measure the magnetic fields in the machine. A complete description of the machine (*Rev. Sci. Instr.* **22** 176 1951), includes the photograph of the ceramic vacuum chamber shown in **Fig. 7-2.**

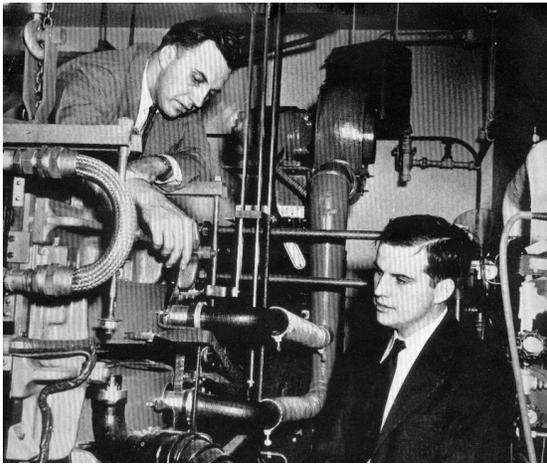
The machine was placed in an underground bunker, adjacent to the south end of the Rockefeller Building. The control room was within the building, and protected from

radiation by thick concrete walls. (As in many other experimental papers from Case for the next decade or two, departmental engineer Mr. August (Gus) Hruschka is thanked, in this case for “most of the construction”.) The photograph of the completed machine (**Fig. 7-3**) was taken when the president of Case, T. Keith Glennan, was showing the machine to the head of the Atomic Energy Commission, Lewis Strauss. (Glennan would later take over the AEC leadership.) **Fig. 7-4** is a photo of Gregg and Shrader in jackets and ties checking out the betatron magnet cooling system.

By 1952, Shrader completed probably the first experiment done with the gamma rays produced by the Case betatron: the measurement from 5 to 13 MeV of the photo-disintegration of the deuteron. This was a very hot topic at the time, as it shed light on the nuclear force which binds the neutron and proton together. Shrader, and his student Victor Krohn, aimed the gamma rays coming from the betatron at deuterons and measured the angular distribution of the outgoing protons. In this case, the deuterons were incorporated in nuclear emulsions impregnated with D<sub>2</sub>O (heavy water).



**Fig. 7-3.** Glennan shows betatron to AEC Chief Strauss.



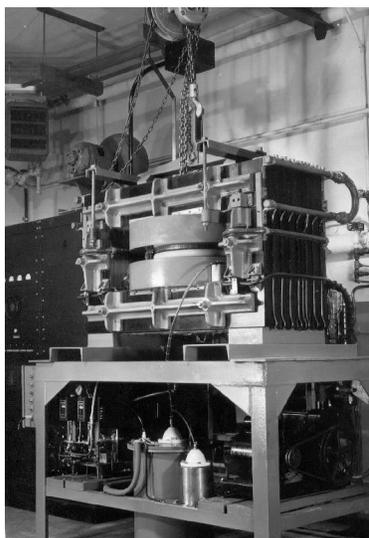
**Fig. 7-4.** Gregg and Shrader, dressed for research.

*The **deuteron** is the simplest nucleus, consisting of a single proton and a neutron. It is bound together by the nuclear or “strong” force and requires an energy of 2.2 MeV to break it apart. It was the object of study by experimentalists and theorists the world-over as a key to understanding the strong force. **Nuclear emulsions** were a widely used technique for observing the tracks of energetic charged particles. They were basically very thick photographic films (without the celluloid backing). Charged particles passing through would ionize the silver salts, and, on development, grains of silver would mark their paths. Measurement of the distance traveled in the emulsion gives the kinetic energy of the charged particle.*

**Fig. 7-5** is a view of the lab in Rockefeller where the detectors were built and tested. It shows a nice assortment of the bulky vacuum tube electronics available in the

1940's. **Fig. 7-6** is a full view of the betatron showing the heavy-duty crane above the magnet coils and iron yoke and the vacuum pumps and cold-traps beneath.

The gamma ray beam was collimated to about a two centimeter diameter. It just grazed the 200  $\mu$  thick emulsion plates so the forward traveling protons would remain in the emulsion. The developed plates are then examined by using a microscope. One sees little strings of silver grains, the tracks ranging from a few microns in length up to a millimeter or two. From known range-energy relations, one gets the energy of the proton which was knocked out of the deuteron. The angle between the proton direction and the direction of the incoming gamma is measured (allowing for the fact that the emulsion thickness after development and drying has shrunk to only one sixth of its thickness during exposure). The energy of the incoming gamma could be calculated from the energy of the proton and its direction. The resulting angular distributions were tabulated for several energy ranges and these were compared with available theoretical predictions. This experiment provided the research topic for Shrader's grad-student, Harold Fleisher. "Photodisintegration of the Deuteron" *Phys. Rev.* **86** 391 1952.



**Fig. 7-6.** The assembled betatron.

field, according to Faraday's law, produces a high voltage between the center and the outer edge of the rotor. This voltage drives a current, via liquid mercury "brushes", through the betatron coil. In their experiment they were able to produce a current of 56,000 amps in three tenths of a second. The current drops off equally quickly as the 30,000 Joules of mechanical energy is drained from the rotor. In their conclusions, the authors suggest that one could build a 1 GeV betatron with two 700 lb rotating disks. They thank Richard L. Garwin who proposed the scheme in the 1947 BS thesis he wrote when he was an undergraduate physics major at Case. "Pulsed air-core series disk generator for production of high magnetic fields" *Rev. Sci Instr.* **22** 578 1951.



**Fig. 7-5.** Betatron control room.

Shrader and Crittenden's graduate student, Robert Strough, published an interesting paper describing a technique for generating quick bursts of electric current. These could be used to produce the pulsed high magnetic fields needed in a betatron. The idea is to use compressed air to mechanically spin-up an 11 lb beryllium-copper rotor to 20,000 rpm. A current is supplied by a battery to a nearby coil, creating a magnetic field in the spinning rotor. This

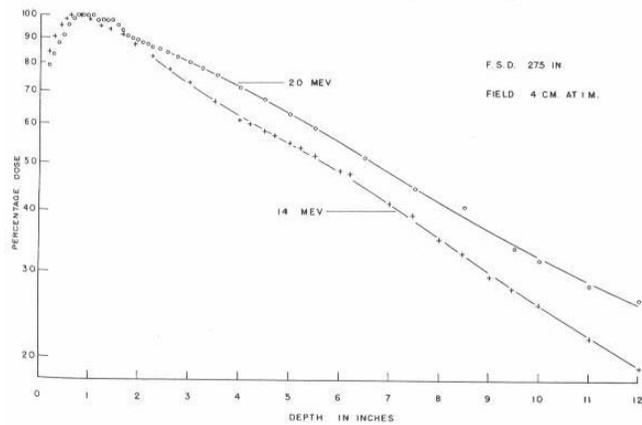
field, according to Faraday's law, produces a high voltage between the center and the outer edge of the rotor. This voltage drives a current, via liquid mercury "brushes", through the betatron coil. In their experiment they were able to produce a current of 56,000 amps in three tenths of a second. The current drops off equally quickly as the 30,000 Joules of mechanical energy is drained from the rotor. In their conclusions, the authors suggest that one could build a 1 GeV betatron with two 700 lb rotating disks. They thank Richard L. Garwin who proposed the scheme in the 1947 BS thesis he wrote when he was an undergraduate physics major at Case. "Pulsed air-core series disk generator for production of high magnetic fields" *Rev. Sci Instr.* **22** 578 1951.

Storing energy in a flywheel became a reality. When I was a grad student working at Brookhaven Lab in the 1960's, I could hear the groaning sound all night long of the big flywheels which every few seconds traded energy with the magnetic fields in the AGS accelerator.

### Gregg and early biophysics

Gregg continued physics experiments using the betatron over the following 10 years. During the same period, however, he became interested in physiology and the applications of ultrasound in medicine. In a paper entitled "Ultrasonics: Biologic Effects" (*Medical Physics* **II** 1132 1950), he described how ultrasound is produced and discussed in detail its effects on small beasts like tadpoles and bacteria and its possible therapeutic uses. (Forty years later, William Tobocman (Chapter 9) would be applying nuclear physics scattering theory to the analysis of the passage of ultrasound waves through biological tissue in medical imaging devices.) Another paper described a device Gregg designed to measure physiological response to vibratory motion, in essence replacing the old-fashioned tuning fork as the tool commonly used by physiologists. This interest in quantitative physiology continued with work on the measurement of pain thresholds and the development of instruments which could provide a measure of neural responses to heat. (*Jour. of Appl. Physiology* **4** 351 1951) A natural follow-up on the measurement of pain was a study of the efficacy of pain-killing medications. (*Jour. of Pharmacology and Expt'l Therapeutics* **106** 1 1952)

In work which combined his interest in things medical with his access to the betatron, Gregg designed a "Roentgen Ray Dosimeter". (*Amer. Jour. of Roentgenology* **76** 979 1956) This small anthracene crystal detector was used to measure the rate of energy deposition at various depths in a water-filled tank, water being a good approximation to living tissue. **Fig. 7-7** shows a typical plot of "dose" versus depth for two photon energies. While usual medical diagnostic x-rays are in the 50 keV range, this work was done at energies available at the CIT betatron: 14 and 20 MeV; it was no doubt related to therapeutic irradiation.



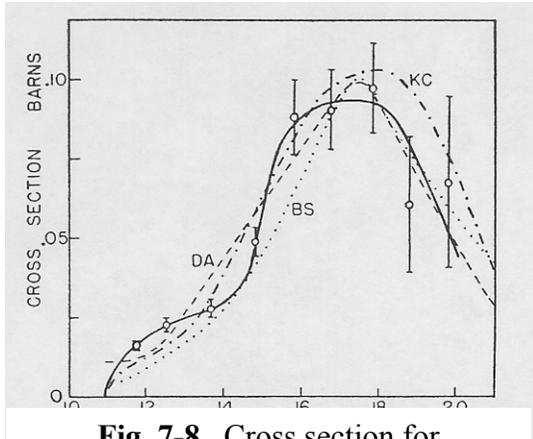
**Fig. 7-7.** Data from x-ray dosimeter: dose vs. depth in water.

### Nuclear physics at the betatron

Shrader continued the nuclear physics program at the betatron. In one experiment beams of gammas at various energies were incident on a  $^{63}\text{Cu}$  target. The gamma knocked out a neutron, leaving a radioactive  $^{62}\text{Cu}$  nucleus. "The  $\text{Cu}^{63}(\gamma, n)\text{Cu}^{62}$  Cross Section" (*Phys. Rev.* **87** 685 1952). The  $^{62}\text{Cu}$  decays with a half-life of 9.7 min by electron

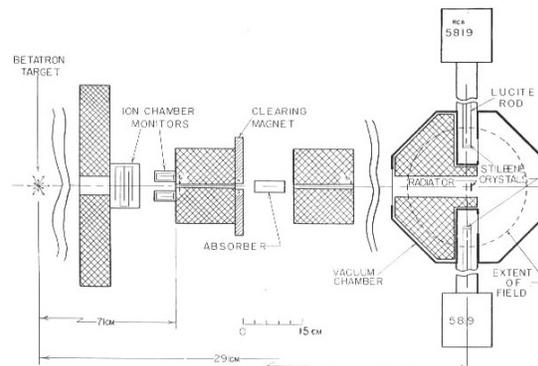
capture and  $\gamma$  emission. The cross section for the reaction was determined by detecting these gammas. **Fig. 7-8** shows the results with the cross section peaking at about 0.1 barn at 18 MeV.

A **barn** is a unit of area  $10^{-28} \text{ m}^2$ ; the name comes from “you couldn’t hit the side of a ...” or maybe “as big as a ...”. The probability that a reaction will take place (the “**cross-section**”) is given as an area because it is related to the effective size of the target particle which is “presented” to the projectile. It can be much larger or smaller than the actual size of the target particle. During the 1940’s and later, cross sections like this were measured for thousands of nuclear reactions, resulting in enormous tables of data (the most famous of which had a picture of a big cow-barn on the cover). These data were essential in the design, for example, of nuclear reactors and weapons, and for the development of models for nuclear structure and even for the syntheses of nuclei in the hot centers of stars.



**Fig. 7-8.** Cross section for  $\text{Cu}^{63}(\gamma,n)\text{Cu}^{62}$ .

Shrader’s next betatron experiment, the measurement of the absorption of gamma rays by heavy metals (Cu, Sn, Pb and U), used a magnetic *pair spectrometer*. All accelerator labs need detectors, and this device was a major addition to the Case Betatron Lab. The spectrometer is shown in cross-section at the right side of the sketch in **Fig. 7-9**. In this experiment, the incident gammas from the betatron pass through a sample of the heavy metal where some of them are absorbed. A known fraction of the transmitted gammas strikes a thin piece of material, the *radiator*. There, in the electric field of an atomic nucleus, the gamma converts into an electron-positron pair. These two particles then enter the spectrometer. There, they travel in opposite directions along circular paths in the magnetic field. Each enters a crystal, making a flash of light which is registered by the RCA photomultiplier tube. With the betatron supplying a steady flux of gammas, the absorber could be remotely placed into and removed from the beam at regular intervals. The change in the counting rate in the spectrometer measures the rate at which the gammas are absorbed by the metal. The absorption cross-sections were measured for the four materials, each at three gamma energies, roughly to about one percent uncertainty. (“Absorption of 5.3-Mev, 10.3-Mev, and 17.6-Mev Gamma-Rays” *Phys. Rev.* **88** 612 1952, with grad students Earl S. Rosenblum and Raymond M. Warner, Jr.).



**Fig. 7-9.** Gamma ray absorption by metals. Pair spectrometer at right.

Shrader and Shankland both served as thesis advisors to W.H. Voelker (Case PhD 1952) who used the 15 MeV  $\gamma$ 's from the betatron to look once again at Shankland's early interest, Compton scattering. The beam, detectors, and coincidence electronics were vastly better than those which Shankland had at his disposal in 1937 (Chapter 6), and the analysis significantly more sophisticated. The resulting differential cross-section compared favorably with the theory of Klein and Nishina. This is a more advanced version of the Compton formula which includes consideration of the electron and photon polarizations.

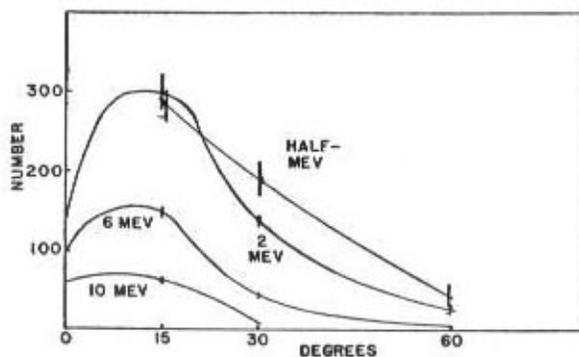
An interesting betatron experiment, with more of a nuclear-physics flavor, was one published in 1960 by Voelker and D.G. Proctor: the photodisintegration of  ${}^6\text{Li}$ . The reactions  ${}^6\text{Li}(\gamma, np){}^4\text{He}$ ,  ${}^6\text{Li}(\gamma, n){}^5\text{Li}$ , and  ${}^6\text{Li}(\gamma, p){}^5\text{He}$  were studied by measuring outgoing protons, neutrons, and proton-neutron coincidences. (*The notation:  $A(a,b)B$  means  $a$  hits nucleus  $A$ , and  $b$  flies away leaving nucleus  $B$* ). The interest in this fairly simple nucleus stemmed from the possibility that it consists of an alpha particle core with an orbiting deuteron. If the incident  $\gamma$  interacts with the deuteron part, then "there should be a strong  $180^\circ$  correlation between the neutron and proton". The experiment did not show such a correlation. "Photodisintegration of  ${}^6\text{Li}$ " *Phys. Rev.* **118** 217 1960; and "Photoneutron crosssections of  ${}^6\text{Li}$  and  ${}^7\text{Li}$ " *Phys. Rev.* **113** 886 1959 by grad students Voelker and Tom Romanowski. Voelker remained in the department as a research associate, responsible for the continued operation of the betatron.

In another betatron experiment published in 1960, new assistant professor **Arthur Benade**, whom we shall meet again in Chapter 12, and his grad student, Robert Chrien, looked at the protons and neutrons ejected from aluminum and copper targets exposed to 20.8 MeV  $\gamma$ 's. They found that photoproton and photoneutron rates were about equal at all energies in aluminum. In contrast, in copper the photoneutron rate rises from two to six times the photoproton rate as the  $\gamma$  energy is raised from 12 to 20 MeV. Aluminum has 13 protons and 14 neutrons, while copper has 29 protons and 34 or 36 neutrons. Many of copper's neutrons sit in an outer shell and are more easily knocked out of the nucleus by the gamma. ("Photoproton and Photoneutron Production in Aluminum and Copper" *Phys. Rev.* **119** 748 1960)

On a slightly different tack, it might be interesting to mention a paper by Shrader (*Nucl. Instru. & Meth.* **13** 177 1961) which describes a new electronic photomultiplier circuit which uses a *tunnel diode*. The significance is that up until this time, detector electronics were based on vacuum tubes, and this was an early step toward the use of "solid state" devices. We shall return to Shrader later in this chapter when the next generation accelerator is built.

**Earle Gregg**, between 1950 and 1960, provided research projects for eleven MS students, and four PhD students, mostly with betatron measurements. Both the detectors employed and the physics studied became progressively more sophisticated. A few examples will illustrate the development of the program:

1. The energies of electrons produced in aluminum by  $\gamma$ 's were measured using a new magnetic spectrometer. The angular distributions for four electron energy ranges are shown in **Fig. 7-10**. ("Energy Spectrum of Electrons Produced in Aluminum by 17.8 MeV Bremsstrahlung", *Phys. Rev.* **102** 1 1956)

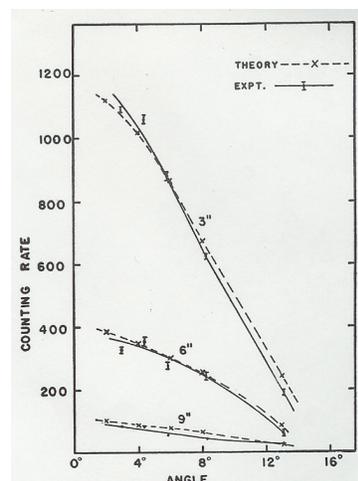


**Fig. 7-10.** Angular distributions for photoelectrons produced in aluminum.

2. Another measurement was of the scattering of  $\gamma$ 's in iron, with sodium iodide detectors; typical angular distributions are shown in **Fig. 7-11**. ("Scattering of High-Energy Gamma Rays", *Jour. Appl. Phys.* **27** 697 1956)

3. Gregg built and tested a magnetic spectrometer which used Compton scattered electrons to determine the energy and relative intensities of the betatron's photon beam. ("Bremsstrahlung Measurements with a Compton Electron Spectrometer" *Phys. Rev.* **105** 619 1957)

At about this time, chairman **Shankland**, who had become interested in reactor physics during his summers at the Idaho Materials Research Reactor, made a very different use of the betatron: a study of the fragments from the fission of  $^{238}\text{U}$  nuclei induced by 17 MeV  $\gamma$ 's. Nuclear emulsions were impregnated with the target uranium atoms, exposed to the collimated  $\gamma$  beam, and then scanned for photodisintegrations. About 1100 events were observed, predominantly having two outgoing tracks. The tracks were measured and the directions of the fission fragments (relative to the beam) were recorded. Shrader had used emulsions as detectors a few years earlier (see above), so the techniques of developing, scanning and measuring emulsions were available to Shankland. The resulting technical report states that the angular distribution was about 90% isotropic, with some indication of a  $\sin^2\theta$  term, i.e. an excess at 90 degrees. Results like this became part of the vast store of experimental data on fission reaction rates and cross-sections.



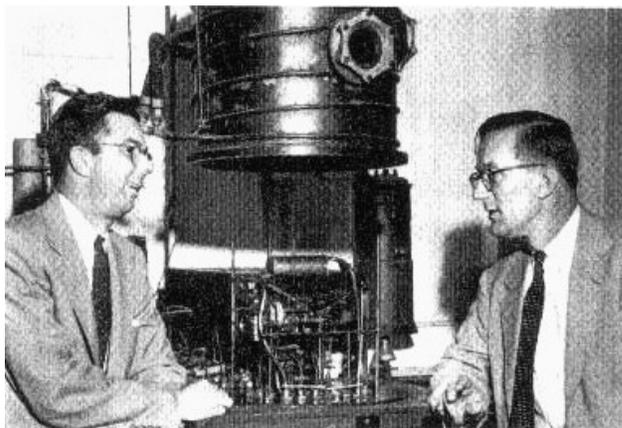
**Fig. 7-11.** Scattering of gamma rays by iron.

Note that up to this point, all of the experiments done with the betatron involved beams of *gamma rays*, and the possibility of producing an external beam of high energy electrons had not yet been realized.

After fourteen years of research, mainly associated with the betatron, Earle Gregg, accompanied by William Voelker, left the department in about 1960 to work on the development of medical instrumentation at the CWRU School of Medicine.

## Smith and condensed matter experiment

We back up a few years to describe the beginnings, in the 1940's, of the Case experimental condensed matter physics program, a discipline which would occupy about half of the department's researchers until the present time. This area of research has been variously called *solid state physics*, *condensed matter physics*, and *materials physics*.



**Fig. 7-12.** Chuck Smith and Polycarp Kusch.

**Charles S. Smith, Jr.** received his DSc from MIT in 1940. He had earned his BS at Case. His doctoral dissertation was on the determination, by x-ray diffraction techniques, of the crystal structure of iron-tungsten alloys. After a yearlong stay at the University of Pittsburgh, he joined the Case department in 1942 where he would remain until 1968. Smith is shown with alumnus Polycarp Kusch in **Fig. 7-12**. Smith's interest in crystal structure and the mechanical properties of solids laid the groundwork for materials research in the department. A

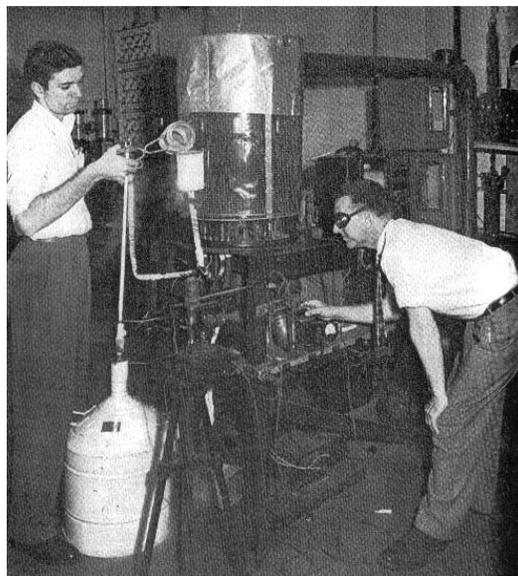
comprehensive paper, written with R. L. Barrett of the Case geology department, appeared in 1947: "Apparatus and Techniques for Practical Chemical Identification by X-Ray Diffraction" (*Jour. Appl. Phys.* **18** 177 1947). The abstract ends with a reader-friendly promise: "The discussion is designed especially for the person who wishes to make use of this important analysis tool but who is not an expert in x-ray diffraction." They covered x-ray sources, cameras, films, sample preparation, measurements and interpretation.

Smith and his student, John R. Neighbours, developed a method for the determination of the elastic constants for cubic crystals by measurements of 10 MHz ultrasound wave velocities in the crystal. (*Jour. Appl. Phys.* **21** 1338 1950) The values of the velocities along the various crystal axes could then be used to determine the elastic constants of nickel (*Jour. Appl. Phys.* **23** 389 1952) and those of a more complex crystal, copper with 4% of its atoms replaced by silicon (*Jour. Appl. Phys.* **24** 15 1953). The work was supported by the Office of Naval Research and the "Case D. C. Miller Research Fund".

*Why are such measurements interesting? Determinations of such things as the elasticity, compressibility, sound velocity, crystal structure, as well as the thermal, electric and magnetic properties of solids, provide the building blocks upon which condensed matter physics is based. Ultimately all these properties must be explained theoretically in terms of how the atoms and their electrons are arranged within the material and how they interact with one another. Even more important, new materials might then be de-*

signed with whatever properties are desired. In Chapter 17, we shall describe the research of the department's theorists who have worked in parallel with the experimenters.

Smith continued his work with ultrasound techniques for over fifteen years, experimentally determining the elastic constants of a dozen metals and alloys and, in each case, comparing the results with current theoretical models. In the process he provided research projects for eleven doctoral and nineteen MS students, much of whose work was published in *Acta Metallurgica* or the *Journal of Physical Chemistry Solids*. Smith and one of his students are shown in their lab in **Fig. 7-13**. In a paper written with Case theorist John Reitz (who will be introduced in Chapter 17), Smith developed a theoretical description for the elastic shear constants for magnesium and magnesium alloys. (*Phys. Rev.* **104** 1253 1956) The elasticity of this close-packed hexagonal structure was found to depend on changes in the "electrostatic energy of the ion cores in the strained and unstrained geometry", as well as the "short range repulsive interaction of the ion cores". Introduction of small amounts of other metals changes the overall electron density, and consequently the interatomic forces. In addition, changes in temperature affect the electron densities, and thus the elasticities.



**Fig. 7-13.** Grad student Fred Anders and Eugene Crittenden cooling vacuum system.

In a 75 page-long review article in *Solid State Physics*, entitled "Macroscopic Symmetry and Properties of Crystals", Smith provides a comprehensive discussion of crystal properties such as resistivity (electric field causes current), pyroelectricity (heating causes electric polarization), piezoelectricity (stress causes electric polarization), elasticity (stress causes volume change), electric susceptibility (electric field causes polarization), and thermal expansivity (heat causes volume change). All these properties were examined along each axis of symmetry of each of several crystal types. (*Sol. St. Phys.* **VI** 175 1958) In Chapter 17 we shall look at these properties from the theorist's point of view.

Smith's papers on ultrasonic measurements of elastic properties of a wide array of crystal materials continue until 1968 when he leaves Case. This line of research was continued by Smith's student, **Donald Schuele**, whom we shall encounter in Chapter 12 as a member of the second generation of Case experimentalists. Smith left the department soon after the federation with Western Reserve, accepting a faculty position at the University of North Carolina at Chapel Hill.

### and thin metallic films

A 1945 paper authored by three of our protagonists, **Olsen, Smith and Crittenden**, introduces a line of research which would be a major activity of the department for the rest of the century: the study of thin films. The paper is entitled “Techniques for Evaporation of Metals” (*Jour. Appl. Phys.* **16** 425 1945). The paper begins: “Evaporation techniques have long been used in the preparation of astronomical mirrors and more recently in the preparation of reflecting and non-reflecting surfaces for many uses. Such techniques, particularly those for evaporating metals, have recently assumed considerable importance because of the scientific utility of thin metallic films and because of the scientific interest in the properties of such films.” They describe their vacuum system (pressure below  $5 \times 10^{-5}$  mm Hg in a bell jar), the first in a six-decade-long sequence of ever more sophisticated vacuum systems to be used in thin film, surface, and optical materials research in the department. In a paragraph for each of 34 metals, from aluminum to zirconium, the writers describe their observations and make their recommendations for the optimum technique to create metallic vapors and films.

A related paper by the same three authors describes a device for measuring the magnetic properties of very small samples of thin metallic films. (*Rev. Sci. Instr.* **17** 372 1946) (A footnote mentions that the work had been done in 1943 under contract to the government. It was thus one of several Case research papers whose publication was delayed until after the war for security purposes.) Crittenden extended this work on magnetism in thin films (*Rev. Sci. Instr.* **22** 872 1951) in a paper in which he acknowledges help from graduate student **Richard Wagner Hoffman**, who will later become the major player in the thin films and surface physics program. (Chapter 12)

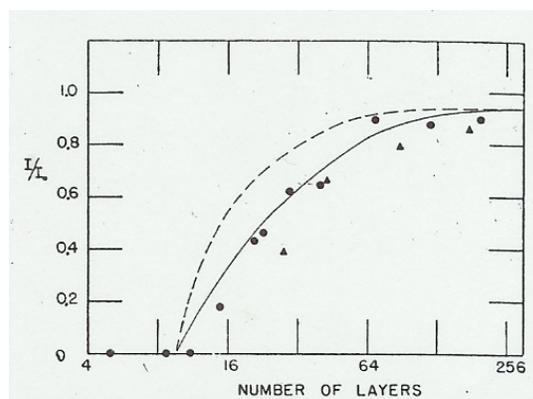
One of Olsen’s undergraduate students at this time, a commuter student from Cleveland Heights, was Donald Arthur Glaser who wrote a 1946 BS thesis on some early experiments in surface physics: “Metal Surface Studies by Electron Diffraction”. Glaser would receive the Nobel Prize in 1960 for his invention of the bubble chamber.

The use of electron beams as a probe of the structure of thin films would be further developed by Crittenden’s student, E. I. Halteman: “Electron Diffraction Evidence for the Existence of Microstress in Evaporated Metal Films” (*Jour. Appl. Phys.* **23** 150 1952).

Crittenden and Hoffman, now his research associate, turned in earnest to the fabrication of smooth, uniform, very thin films: as thin as a few atomic layers. They worked on techniques to minimize impurities at the surface and to spread the material evenly across the glass substrates. From their paper, “Thin Films of Ferromagnetic Materials” (*Rev. Mod. Phys.* **25** 310 1953): “It is recognized that evaporated metal films have acquired a bad reputation as far as being specimens of metal which may be directly compared with pure bulk specimens of the same material.” They comment on surface impurities: “Connected with this is the lack of true protection offered by vacuum of the order of  $10^{-5}$  mm of mercury, for which each surface atom is hit approximately once every half-second by a residual gas molecule.” The properties of interest are the electrical resistance

and magnetization, and their temperature dependence for each type of film. From the theoretical point of view, these properties depend on the disposition of the electrons in the film, a configuration clearly different from that in the bulk material. From the applied physics point of view, these properties determine the applicability of these films to electronic devices and other technologies. In this case, the metal studied was nickel, as pure as they could obtain. **Fig. 7-14** shows, for example, how the extent to which a film can be magnetized drops off rapidly as the film thickness is reduced to a dozen or so atomic layers. Films thinner than this are difficult to magnetize because they apparently break up into disconnected islands of atoms.

Crittenden and Hoffman did further experiments to learn how the atoms in metallic thin films arrange themselves. These involved measurements of electrical resistivity and of the mechanical stress within the films. (*Jour. Appl. Phys.* **24** 231 1953) They looked at the residual stress in the films as a function of the temperature at which the film is laid down, and of the temperature and amount of annealing. (The techniques for the measurement of stress will be described in Chapter 12.) From this, one can learn about the role of vacancies in the film and the tendency of the atoms to coalesce. More explicitly, the abstract of a paper submitted to the *Journal de Physique et le Radium* provides a compact description of the types of things they were looking at. "Purity of the material, protection from chemical reaction with residual gas after deposition, crystal size and preferred orientation, crystal imperfections, mechanical stress, roughness and agglomeration are discussed. The transition metals are well behaved, the noble metals poor, and Zn, Cd, and Hg very difficult to deal with as regards producing smooth surfaced films down to a few atoms thick." (*Jour. Phys. et Rad.* **17** 179 1956) The goal was to create high quality uniform thin films. Grad students Harold Story and Ned Razor worked on the development of techniques to quantify lattice defects and stress caused by annealing. Hoffman and an army of grad students and post-doc research assistants continued this work on thin films for several decades, as will be described in Chapter 12.



**Fig. 7-14.** Thin nickel film magnetizability vs. thickness.

**Eugene Crittenden** left the department around 1956, taking a faculty position at the Naval Postgraduate (NPS) in Monterey, CA. At Case he had directed the research of nine masters and three doctoral students. In his new position, he would initiate a research program in electro-optics and other areas of special interest to the Navy, such as infrared search and tracking systems and optical atmospheric turbulence studies.

Four years later, **Leonard Olsen** resigned from Case and joined Crittenden in Monterey, where he established a physics baccalaureate program. Olsen devoted his efforts to improving the teaching of physics, including a term as president of the AAPT (American Association of Physics Teachers). Both Olsen and Crittenden were active in

faculty governance at the NPS, each serving as president of the AAUP (American Association of University Professors) chapter. Olsen retired from the NPS in 1975 and lived until 1981.

### The Case van de Graaff

In 1961, **Erwin Shrader** spent some time at the High Voltage Engineering Corporation's plant in Massachusetts. This company's principal product was electrostatic particle accelerators, specifically van de Graaff accelerators.

*The van de Graaff machines were capable of producing external beams of protons or other charged ions with energies of millions of electron volts. They were simply large versions of the popular demonstration machines which thousands of high-school kids have used to make their hair stand on end. An endless belt wrapped around two pulleys is driven at high speeds. A set of conducting whiskers gently brush the belt as it sweeps by, and electrons jump from the belt to the brushes, leaving the belt positively charged. As the other end of the belt passes near a second set of brushes, electrons jump from the brushes to the belt. That leaves a big positive charge on the large metal dome attached to these brushes. The resulting electric potential difference between the dome and ground is used to accelerate protons (i.e. hydrogen ions) or other ions through an evacuated pipe, whence they are directed out of the machine by a bending magnet.*

Shrader's visit to HVE was no doubt connected with plans by Case to buy one of these machines. While there, he co-authored a paper entitled "Production of High Intensity Ion Pulses of Nanosecond Duration". (*Nucl. Instruments and Meth.* **12** 335 1961). This paper described a rather sophisticated set of dipole bending magnets, quadrupole focusing magnets, and radio-frequency electric fields which operate on the ion beam after it exits the van de Graaff. The arrangement delivered 3 MeV "ion bursts of less than one nanosecond duration at a peak current of several milliamperes." The system could also be modified to produce short bursts of *neutrons* from the reaction  $^{55}\text{Mn}(p,n)^{55}\text{Fe}$ . The pulsed nature of the beam would allow the measurement of the lifetimes of nuclear states produced in beam-target collisions because the experimenter would know both the time at which the state was produced and the time it decayed. **Bob Leskovec**, an engineer hired in 1967 as staff physicist, was responsible for the design of the electronics related to the timing of the beam. He is still (in 2005) a member of the university's technical staff; he describes the project in a recent memo: "My first task in 1967 was to develop a "stop-signal" synchronizing system to get a stable lock to the beam pulse for the time-of-flight technique. This was so exciting because we were just at the transition from vacuum tube technology and I was able to pull it off with an entirely "solid state" design using some new devices called tunnel diodes".

### Making room: the new wing

Before the van de Graaff could be installed, suitable space had to be prepared for it. This involved a three story high hall for the machine whose belt ran vertically, and large underground experimental areas enclosed by thick concrete walls. This was the op-

portune time for the Case department to build a large addition to Miller's Rockefeller Building. A three-story brick structure, 75 by 90 feet, was built south of Rockefeller, with its central hallways on each floor placed end to end with those in Rockefeller. The new building had large research laboratory spaces in the basement and three stories of offices, research labs, teaching labs, and class-room spaces above. The new accelerator space was incorporated on the basement and ground-floor levels. An adjacent 600 seat auditorium (named Strosacker) for use by the whole institute was part of the same construction project, and its "basement" area of 75 by 110 feet was added to the physics laboratory space. **Fig. 7-15** shows three views of the construction, with emphasis on the large concrete shielding surrounding the van de Graaff area. (The new building would cover up seven of the physicists' names which were placed over the windows of the old building by Miller in 1905.)

The Case machine was up and running by 1960, with the expert help of engineer Lawrence Hinkley. He is shown, with hand in pocket, checking out the external beam electronics in **Fig. 7-16**. **Fig. 7-17** shows the beam exit ports and part of one of the larger detectors. Larry would become known as "the only person who could get the van de Graaff to run".



**Fig. 7-16.** Larry Hinkley and the van de Graaff.

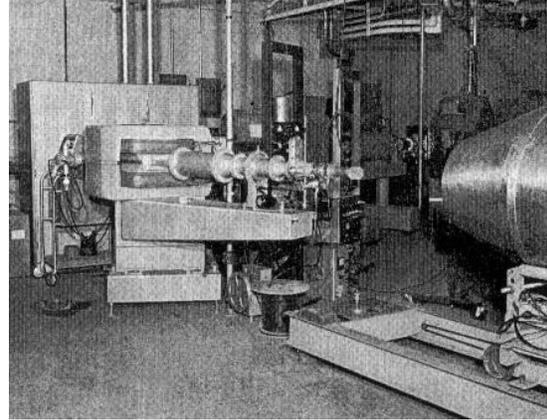


**Fig. 7-15.** Construction of the south wing of Rockefeller.

An early experiment was designed to study a narrow excited state in the calcium nucleus. Protons from the van de Graaff were incident on a target of  $^{39}\text{K}$  nuclei. The K nucleus absorbed the proton, becoming  $^{40}\text{Ca}$  in an excited state. These excited nuclei then returned to the ground state by the emission of a photon. These photons were then directed at other Ca nuclei which could absorb them, and become raised to the same excited state. However, these photons in general had a bit less energy than the required excitation energy, because the nucleus which emitted them stole some away as recoil kinetic energy.

Now here is the tricky part: the energy of the photon would be boosted (Doppler shifted) to the required level if

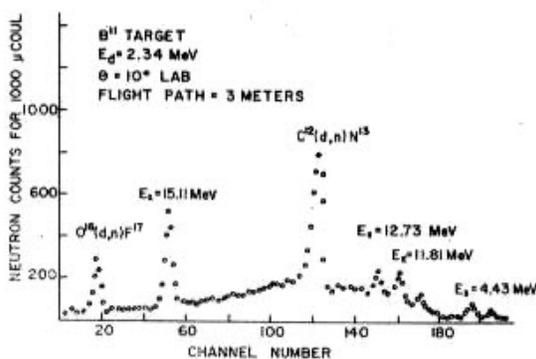
the nucleus which emitted it were moving with just the right speed in the same direction as the photon. The excited Ca nucleus was indeed moving, having been struck by the proton. If one chose all the angles correctly, the photon could have exactly the right energy to be reabsorbed by the second Ca nucleus, thus being removed from the beam. This technique allows one to measure precisely the energies and the widths (and lifetimes) of the excited state – important data for checking nuclear models. In this case, the excitation energy was 10.3 MeV and its width, coincidentally, one-millionth of that, or 10.3 eV. For a state with such a narrow width, the re-absorption could never have taken place without the Doppler trick. (*Phys. Rev.* **124** 1541 1961 with grad student Alan C. Eckert) This technique of observing resonant absorption by moving the target nucleus or, in this case, the source nucleus would become widely used in the study of very narrow states.



**Fig. 7-17.** Beam chopper at exit from van de Graaff.

### Pulsed MeV beams

"A Nanosecond Pulsed Accelerator Facility" is the title of a paper by Shrader *et al.* in "*Nuclear Electronics II*", a compilation by the International Atomic Energy Agency, Vienna 1962. The ability to produce very short bursts of protons is essential for experiments in which the protons are used to generate neutrons (as mentioned above in the  $^{55}\text{Mn}(p,n)^{55}\text{Fe}$  reaction), and where the energies of the neutrons are determined by time-of-flight, i.e. the time it takes them to travel a given distance in the laboratory.



**Fig. 7-18.** Excited states in carbon 12.

way alone. The measured energy of this neutron determines the total energy (or mass) of the residual carbon nucleus, thus giving the excitation energies in the carbon. (I have al-

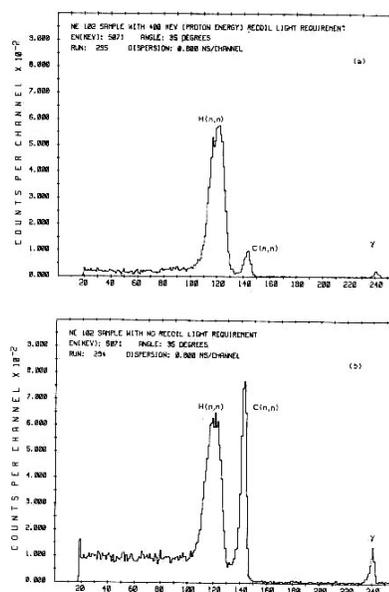
It is amazing how many different ways our players found to use the van de Graaff. As an example, they wanted to study the excited states in the  $^{12}\text{C}$  nucleus. Their approach is rather round-about and is not the first one to come to mind. For one thing, they had experience with detecting and measuring the energies of neutrons. For another, the van de Graaff could accelerate deuterons as well as protons. The deuterons were incident on a target of  $^{11}\text{B}$ ; then, in a "stripping" reaction, the proton was left behind in the B nucleus, making it  $^{12}\text{C}$ , and its faithful companion neutron continued on its

ways been fascinated by the fact that when you break up a deuteron like this, you separate the proton and neutron which have been partners for fourteen billion years or so.)

The experimental results could be checked by varying the energy of the incident deuterons (1.6 to 2.7 MeV). In addition to observing well-defined excited states, as illustrated by the sharp peaks in **Fig. 7-18**, they found that many neutrons came from collisions in which the target nucleus was entirely disrupted, with pieces flying out in all directions. This experiment, as earlier ones, relied on the short-pulse capabilities of the accelerator. (“Neutron Producing Reactions by Deuteron Bombardment of  $B^{11}$ ”, *Phys. Rev.* **129** 1275 1963) A follow-up experiment added the detection of the  $\gamma$ 's coming from the excited  $^{12}C$ , in coincidence with the arrival of the neutron. (“Angular Correlation in the  $B^{11}(d, n\gamma 1511 \text{ MeV})C^{12}$  Reaction” *Phys. Rev.* **131** 2594 1963 with grad student Hee J. Kim.)

### Detecting the neutron

In experiments at the van de Graaff in which secondary neutron times-of-flight were measured, the arrival of the neutron was usually detected by the observation of a recoil proton in a scintillator. In all such materials, there are both hydrogen and carbon nuclei, and, in order to determine absolute cross-sections, it is necessary to identify those events in which the neutron scattered off a hydrogen nucleus. Shrader and his students looked into this problem and found that if one measures the intensity of the light produced in the scintillator, the proton events, which produce much more light, can be isolated. **Fig. 7-19** shows the scattered neutron times-of-flight, with (the upper plot) and without (the lower plot) the requirement of a bright flash of light. The peak on the left side is from proton events. The separation is quite good. *Nucl. Inst. and Meth.* **85** 151 1970 “Absolute Normalization of Neutron Scattering Cross Section Data Using Organic Scintillators as Scatterers.”



**Fig. 7-19.** Neutron time-of-flight plots showing separation of H from C events.

Between 1947 and 1970, Shrader advised 12 doctoral students, 18 masters students, and a large number of bachelors degree students, including Richard Garwin who, for the past 40 years, has been one of the country's most prominent physicist advisors to government on nuclear arms issues. Considered in some respects to be the “father of the hydrogen bomb”, Garwin is one of Case's most illustrious graduates. Another of Shrader's BS students was Jonathan Reichert whom we shall meet in Chapter 14 when he joins the CWRU faculty. Erwin Shrader left the department in 1970 for a position at Harshaw Chemical Company, a manufacturer of the scintillator materials used in particle detectors.

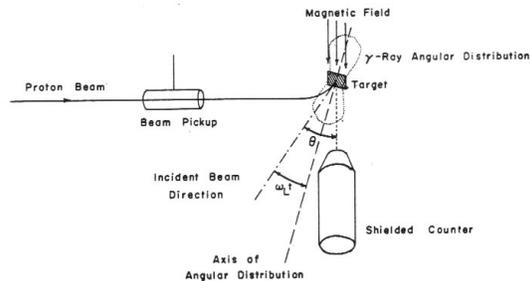
## Scharenberg and Silverstein and the van de Graaff

**Rolf Paul Scharenberg** joined the department in 1961 having earned his doctorate at Michigan in 1954. **Fig. 7-20.** While he remained at Case for less than five years, he completed a series of measurements of the magnetic moments of nuclear excited states, continuing work initiated by Shrader. Recall that the van de Graaff accelerator delivers 2 MeV protons in nanosecond pulses. As these pass through a tungsten target, some  $^{184}\text{W}$  nuclei are excited from the spin 0 ground state to an excited rotational state with spin 2. An external magnetic field of around 40 kilogauss causes these nuclei to precess. As they do so, they decay exponentially (mean life  $1.85 \cdot 10^{-9}$  s) to the ground state, emitting a 111 keV gamma ray. The outgoing  $\gamma$ 's are detected at various angles in the plane of the  $\gamma$  and incident proton. The time at which the nucleus is excited is marked by a signal from the incident proton pulse, and the timing of the hits in the



**Fig. 7-20.** R. P. Scharenberg.

$\gamma$  counter can be unfolded to give a rate of precession, and therefore, a measure of the magnetic moment of the excited state. Knowledge of the magnetic moment of the excited nucleus allows one to determine the relative contributions of the protons and neutrons in the collective flow within the nucleus. (*Phys. Rev.* **137** B26 1965) The sketch in **Fig. 7-21** is from the PhD thesis of Paul J. Wolfe. In 1969, after five years at Case, and having been promoted to associate professor with tenure, Scharenberg decided nevertheless to pursue his nuclear properties research at the Angular Correlation Laboratory at Purdue University.



**Fig. 7-21.** Setup to measure magnetic moments of nuclear excited states.



**Fig. 7-22.**  
E. A. Silverstein.

Chairman Reines clearly wanted to get the most out of the van de Graaff program. The Case department added another young nuclear experimentalist in 1964. **Fig. 7-22. Edward A. Silverstein** had completed his PhD in 1960 at the University of Wisconsin under H. T. Richards. His thesis was on  $^4\text{He}$   $^{14}\text{N}$  and  $^3\text{He}$   $^{16}\text{O}$  elastic scattering. The object was to detect bumps in the cross-section which correspond to excited states in  $^{18}\text{F}$  and  $^{19}\text{Ne}$ . Subsequently, he spent  $2\frac{1}{2}$  years at the University of Padua where he helped install a new van de Graaff accelerator. He would be very useful in the operation and utilization of the Case machine. Silverstein had developed expertise in experiments involving the scattering from gas targets, and he set up an experiment to study proton-proton bremsstrahlung at 3.2 MeV. This required the identification of the small number of events corresponding to  $pp \rightarrow p\bar{p}\gamma$

in a sea of elastic scattering events (a few dozen out of 400 million). “Proton-proton bremsstrahlung at 3.2 MeV” *Phys. Rev. Lett.* **21** 922 1968.

Silverstein would later work with Phil Bevington in a search for a three-neutron bound state. This work is described in Chapter 16. In 1969 Silverstein took a position at the radiology department Milwaukee County General Hospital where he would apply his expertise in particle detection.

With the departure of Olsen, Crittenden, Gregg, Smith and Shrader, the first major phase of experimental physics at Case came to an end. While Hoffman and Schuele continued the thin film and the materials programs, the pendulum would begin to swing toward subatomic research.