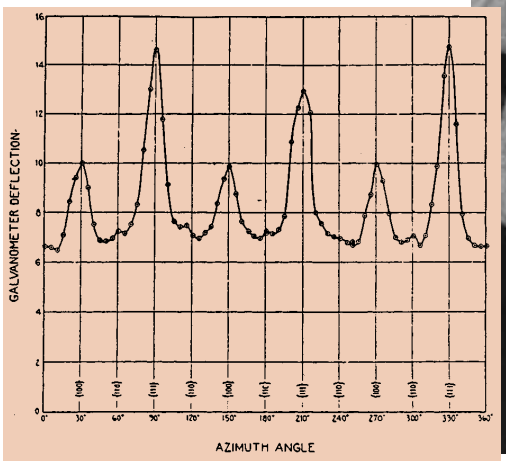
Right: Clinton Davisson and Lester Germer with the apparatus they used to establish the wave nature of electrons. (Courtesy AT&T Archives)

Bottom: Graph from their 1927 Nature *article showing diffraction peaks observed in electron scattering from a nickel crystal.*



metal, thereby making it easier for electrons to escape from the surface—and substantially reducing the amount of power needed to heat a filament. Such a fundamental understanding of the physics of electrons proved crucial to further engineering advances in vacuum tubes that saved AT&T millions of dollars annually.

IN THE LATE 1920S and early 1930s, Felix Bloch, Rudolph Peierls, Alan Wilson and other European physicists laid the foundations of modern solid-state physics in their theoretical studies of how waves of electrons slosh about within the periodic potentials encountered inside crystalline materials. Their work resulted in a theory of solids in which there are specific allowed (or forbidden) energy levels—called "bands"—that electrons can (or cannot) occupy, analogous to the Bohr orbitals of early quantum theory. Combined with practical methods of calculating these band structures in actual substances, pioneered by Eugene Wigner, band theory fostered a better understanding of why certain materials act as electrical conductors and others as insulators. And, in a decade when electron tubes reigned supreme as the active components of electronic circuits, band theory began to elucidate the properties of intermediate materials called semiconductors, whose myriad spawn would eventually supplant these tubes throughout electronics.

World War II spurred tremendous practical advances in the technology of semiconductors, largely due to the fact that microwave receivers needed rectifiers able to operate above a few hundred megahertz, where electron tubes had proved useless. Crystal rectifiers, with a delicate metal point pressed into a germanium or silicon surface, filled the gap nicely. By the end of the War, methods of purifying and doping these substances to make easily controlled, well-understood semiconductors had been perfected by scientists at such secret enclaves as the Rad Lab at MIT and Britain's Telecommunications Research Establishment at Great Malvern.

No laggard itself in these pursuits, Bell Labs led the way during the postwar years in applying wartime insights and technologies to the creation of practical new semiconductor components. "The quantum physics approach to structure of matter has brought about greatly increased understanding of solid-state phenomena," wrote its vice president Mervin Kelly—another of Millikan's grad students—in 1945, authorizing formation of a solid-state physics group. "The modern conception of the constitution of solids that has resulted indicates that there are great possibilities of producing new and useful properties by finding physical and chemical methods of controlling the arrangement of the atoms and electrons which compose solids."

The most important postwar breakthrough to occur at Bell Labs was the invention of the transistor in late 1947 and early 1948 by John Bardeen, Walter Brattain, and William Shockley. And a key to their interpretation of transistor action was a new physical phenomenon Shockley dubbed "minority carrier injection"—in which electrons and positively charged quantum-mechanical entities called "holes" can flow by diffusion in the presence of one another. Once again, a detailed scientific understanding of how individual subatomic particles (and what, in certain respects, act like their antiparticles) behave proved crucial to a pivotal advance in electronics.

The transistor happened along at a critical juncture in technological history. For the electronic digital computers that also emerged from wartime research could not have evolved much further without it. The thousands of bulky, fragile electron tubes used in such early,