with ε_a and Δ_a, the resonance position and width, depending upon the particular state, $\rho_m(\varepsilon)$ the substrate density of states, w_a the "radius" of the atomic state, $\kappa(\varepsilon) \approx [(2m/\hbar)(\phi_e-\varepsilon)]^{1/2}$, and φ_e the workfunction of the tip. Observed structure in the TED that provides the desired spectroscopic information arises from $\rho_a(\varepsilon)$. The enhancement is mainly a consequence of the fact that now the rate-limiting step is tunneling from the adsorbate to vacuum, through a barrier that is reduced compared to the full direct metal-vacuum tunneling barrier. This enhancement is accounted for by the exponential factor. As was noted in the original paper [1], this realization of resonance tunneling involving an adsorbed atom (discrete state mixed with a continuum) can be (and was!) put in one-to-one correspondence with the Fano lineshape theory [4] which is the topic of another NBS/NIST classic publication outlined in this volume.

The initial spectroscopic experiments were carried out for single zirconium atoms deposited on a tungsten field emission tip; the published TED ratio is shown in Figure 3 together with two "relatively good fits" to the theoretical curve. This spectrum, crude even by standards a year later, nonetheless was a landmark. It expressed the first confirmation of the rather speculative beliefs of the time that the electronic energy level spectra of adsorbed atoms were related to the free atom spectra shifted and broadened ~1 eV by interaction with the surface. Refined and extended presentations of this study soon followed which reached a much wider audience [5,6].

An unusually creative and imaginative period of research by the three coauthors over the next few years produced a wealth of new insights into the microscopic aspects of surfaces. The surface topografiner [7] invented and constructed by Young during this time period (and discussed elsewhere in this volume) was an initial version of the scanning tunneling microscope for which the 1986 Nobel Prize in Physics was awarded to Binnig, Rohrer, and Ruska. The field emission spectroscopy work of this period (mostly from NBS) has been summarized and reviewed by Gadzuk and Plummer in their *Reviews of Modern Physics* article [8], which is still one of the most definitive and comprehensive sources of widely used information and wisdom on this topic. The theory of resonance tunneling developed during this period is applicable in many areas of current interest and activity, for instance resonance tunneling in nanostructures such as quantum wells, quantum dots, and in the STM , as discussed in the 1993 *Physical Review* paper by Gadzuk [3].

The members of the trio have followed varied life trajectories over the ensuing decades. In 1973 Plummer joined the faculty at University of Pennsylvania, where he served as director of the Materials Research Laboratory from 1990 to 1992. Since 1992 he has held a joint

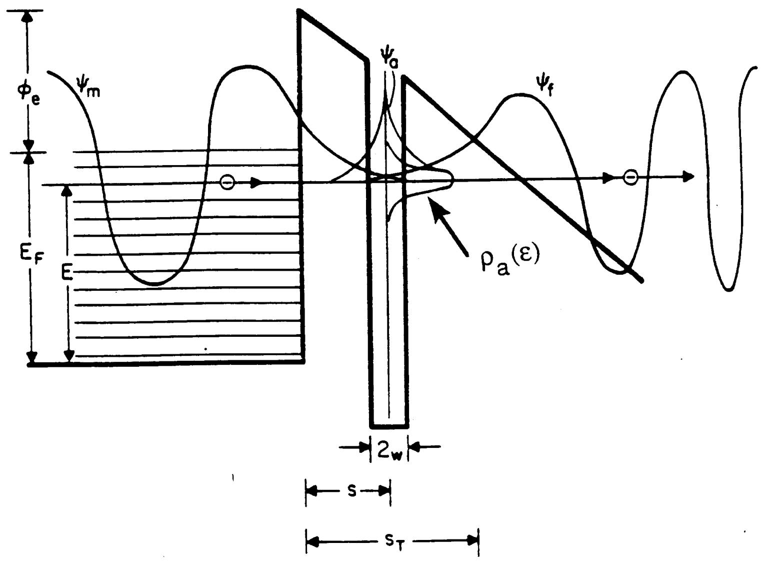

Fig. 2. Schematic model showing the idealized potentials relevant in field-emission resonance tunneling. The electron wave functions are: ψ_m, the unperturbed metal function; ψ_a, the localized adsorbate resonance function; and ψ_f, the emitted electron function. The adatom centered at $z = s$, with diameter equal to $2w$, shows a Lorentzian-like local density of states labeled ρ_a.