Electron Emission Models for Simulation

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RECAP

P^3 WORKSHOP 2021
November 10-12, 2021

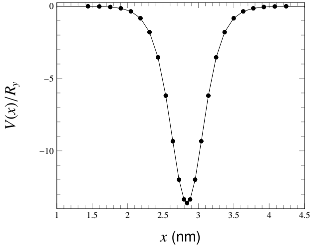
We gratefully acknowledge:
(NRL), A. Shabaev, M. Osofsky, S. Lambrakos; (USNA) D. Finkenstadt;
(Leidos) J. Petillo; (AFRL) J. Riga, D. Shiffler; (ASU) O. Chubenko;
(LANL) D. Dimitrov, N. Moody, A. Neukirch, J. Smedley, S. Tretiak

Reflectionless Transmission

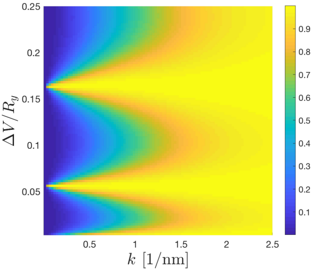
Pöschl-Teller (PT) well (sech^2 potential) See Ref. 5

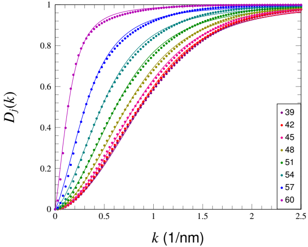
$$V_{pt}(x) = -\frac{\hbar^2 \nu(\nu+1)}{2ma^2} \text{sech}^2(x/a) \qquad (21)$$

Integer ν, $D(k) \to 1$ = *all* incident e^- for a particular $k = \sqrt{2mE}/\hbar$ are transmitted (yellow)



TMA Analysis gives $D(k)$: x_j points shown





Modify $D_\triangle[E(k)]$ (Eq. 2) by k_a and r from fits

$$D(k) \approx \frac{k^r}{\left(k^{2r} + k_a^{2r}\right)^{1/2}} \qquad (22)$$

Wave Packet on Delta Barrier

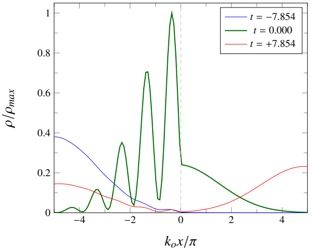
Delta Function Barrier: $V(x) = (\hbar^2 \gamma / 2m)\delta(x)$

Wave function

$$\psi_k(x) = \begin{cases} e^{ikx} + r(k)e^{-ikx} & (x < 0) \\ t(k)e^{ikx} & (x > 0) \end{cases} \quad (23)$$

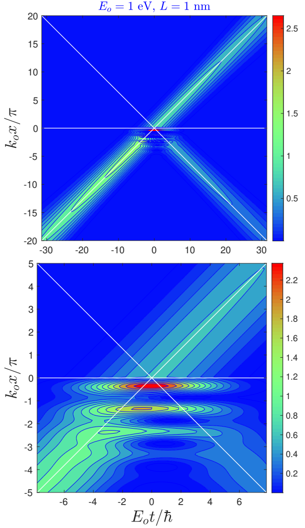
$$r(k) = -\frac{i\gamma}{2k + i\gamma}; \quad t(k) = \frac{2k}{2k + i\gamma} \quad (24)$$

$$D(k) = |t(k)|^2 = 4k^2/(4k^2 + \gamma^2) \quad (25)$$

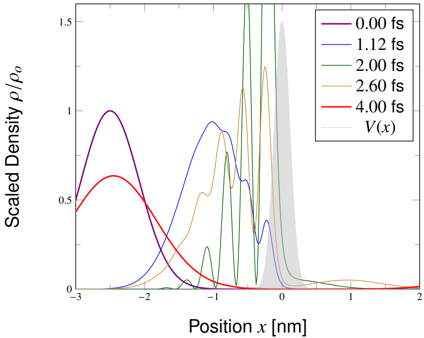


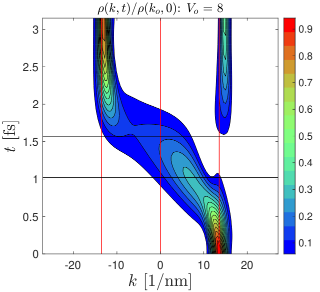
See Ref. 1: Above: gaussian wave packet hitting δ-barrier
Right: $\rho(x,t)$ as contour plot: Horizontal white line $x = 0$
Diagonal white lines = ballistic equations $x_\pm(t) = \pm \hbar k_o t/m$.

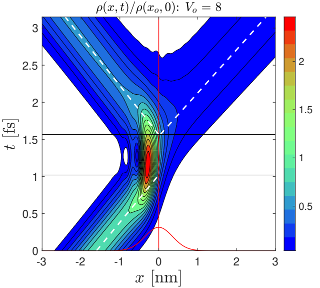
Ballistic model (white diagonals): $x(t) = x_o \pm \hbar k t/m$



Transmission and Reflection Delay (TARD) Model I

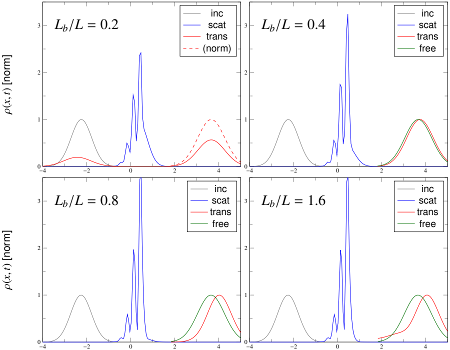






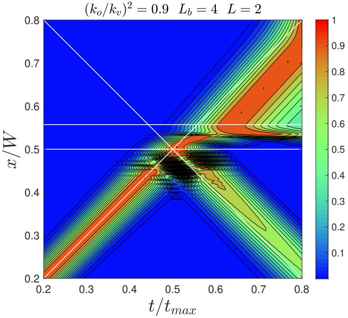
- (*above*) Standard representation of $\rho(x,t)$ for $E_o = 4.5$ eV: transmitted is mostly tunneling. Shaded = $V(x)$. 5 snapshots
- (*right top*) Contour of $\rho(k,t)$: locations of peaks define $k_r = -13.1140$ nm^{-1} and $k_t = 14.8152$ nm^{-1} (TARD k). Vertical red lines are at $k = \pm k_o = \pm 13.5546$ nm^{-1} and $k = 0$.
- (*right bottom*) Contour of $\rho(x,t)$: two horizontal black lines defined by crossings at $(x = 0)$, separated by $= 0.5461$ fs. This is the TARD time
- See Ref. 3

Rectangular Barrier



Wave Packets incident on rectangular barrier

Gray and blue lines normalized to incident max. For Case (0.2), solid red line normalized to incident max, and dashed red line to max of transmitted (red) portion; in cases (0.4, 0.8, 1.6), red lines all normalized to transmitted max. Green line is free wave packet normalized to its max, evaluated at the same time as "trans"



$\rho(x,t)$ normalized to max of each t slice

$L = 2$ nm, $L_b = 4$ nm, $E_o = 1$ eV, $E_o/V_o = 0.9$, wave packet incident on rectangular barrier. Delay associated with reflection evident in how contour lines depart from white ballistic lines.

Triangular Barriers

- Propagating gaussian wave packet
- $\rho(x,t)$ norm to each t slice for triangular (Fowler Nordheim) barrier
- horizontal = time, vertical = position
- $F_o = q|\mathcal{E}|$ as shown
- White curved line for $x > x_o = W/2$, where $W = 50$ nm, corresponds to $x_b(t)$
- Both reflected and transmitted show TARD
- Color bar and axis labels $(t/t_{max}, x/W)$ are same as before.