

## I. DOUBLE-BARRIER RESONANCES

In this lab you will use the computer programs *bound-states* and *quantum-tunneling* for studying the resonances of a double-barrier potential. These programs were developed by the project PhET. You find the programs under

<http://www.tp.umu.se/~lundh/kvel/>

Versions in other languages are available at

<http://phet.colorado.edu/en/simulation/quantum-tunneling>

The results are to be reported orally at the end of the class. If you do not finish in time, you should write a short report about your results. Explain what you have done and answer all the questions.

### A. Exercise

a) Calculate by hand the eigenenergies for an electron in an infinite square well of width 2 nm. Write down the energies in electron volts for the first four levels, in the table below.

Level	Result of (a)	Result of (b)

b) Use *bound-states* to compute the bound state energies for a potential well of width 2 nm and depth 1 eV. Put them in the table above. Are they similar to those in a)? Why?

c) Use the program *quantum-tunneling* and choose a double barrier. Choose the distance between the wells to be 2 nm and the height of the potential to 1 eV. This you can do using the button “*Configure energy..*” Choose the incoming wave function to be a plane wave. (Buttons on the right side.) Also tick the box “*Show reflection and transmission probabilities*”. Finally, in “*Configure energy..*” you can set the value of the energy of the incoming wave. What happens if you choose an energy close to one of the values calculated in b)? Write down the transmission probability for a range of 4-5 energies around these and include them in the table below.

(That is, if your lowest bound-state energy was 0.07 eV, then record the value of T for 0.05, 0.06, 0.07, 0.08 and 0.09 eV. Same for the others.)

First bound-state energy : \_\_\_\_\_ eV

Barrier width : \_\_\_\_\_ nm

Barrier position 1 : \_\_\_\_\_ nm

Barrier position 2 : \_\_\_\_\_ nm

E (eV)	T

Second bound-state energy : \_\_\_\_\_ eV

Barrier width : \_\_\_\_\_

Barrier position 1 : \_\_\_\_\_

Barrier position 2 : \_\_\_\_\_

E (eV)	T

Third bound-state energy : \_\_\_\_\_ eV

Barrier width : \_\_\_\_\_

Barrier position 1 : \_\_\_\_\_

Barrier position 2 : \_\_\_\_\_

E (eV)	T

Fourth bound-state energy : \_\_\_\_\_ eV

Barrier width : \_\_\_\_\_

Barrier position 1 : \_\_\_\_\_

Barrier position 2 : \_\_\_\_\_

E (eV)	T

If you find only  $T=0$ , then decrease the barrier widths. Make sure to choose barrier positions *and* widths so that the *space between* the barriers is 2 nm wide!

These special energy values are resonances. What is the shape of the wave function between the wells for the first, second, third, and fourth resonance?

c) Now look at the time development for an incoming *wavepacket*, instead of a plane wave. Choose a large *initial width* for the wave packet, and take the initial position to be far enough from the barriers. Try different initial energies for the Gaussian wavepacket, both close to and far from the computed resonance energies. (Skip the lowest resonance energies if they are difficult to zoom in on.) When you change your energy from, say, 0.57 to 0.58 eV, do you see a change in transmission? Why/why not? How far from a resonance do you have to go before you can see with your bare eyes that the transmission has decreased?

Why did you have to choose a wide wavepacket in order to see an effect?