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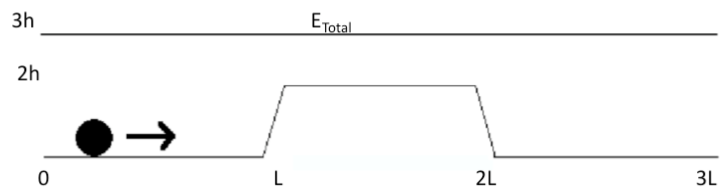
Tutorial: Quantum Tunneling with PhET Simulation

Part A: Classical Particle

A ball of mass *m* rolls to the right on a flat, frictionless surface with total energy $E = 3mgh$. The ball soon encounters a sloped surface and rolls up to height $2h$. After, the ball rolls back down the ramp, always staying in contact with the surface.



1) Is the total energy of the ball as it rolls from 0 to 3L increasing, decreasing, or staying the same?

2) Sketch the kinetic energy, gravitational potential energy, and total energy of the ball between 0 and 3L. Scale your graph with multiples of mgh.

3) Is the amount of time the ball spends between L and 2L greater than, less than, or equal to the amount of time it spends between 0 and L? How does it compare to the amount of time it spends between 2L and 3L? (Ignore the time the ball spends on the ramp.)

4) Now imagine that we take a photograph of the ball at some random time. Is the probability of finding the ball between 0 and L greater than, less than or equal to the probability of finding it between L and 2L? Why?

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PART B: Quantum Particle with E > V (Using PhET sim)

1) Observe the plot of the wave function for plane wave solutions for the case where E > V. Where does the time-dependent oscillation come from mathematically? Describe how the frequency of oscillation changes as you change E.

2) Now widen the width of the wire gap (where V > 0) to 3.5 dashed-lines wide. How does the wavelength of the wave function in this region compare to the wavelength in the region to the left? How about to the region on the right? Lastly, how do the wavelengths in the regions on the left and right compare to each other?

3) What does your answer to (2) tell you about the kinetic energy of the particle in each of these three regions? Be sure to discuss this with your group members.

4) Now refer back to the classical particle case. How does the kinetic energy of the classical particle from L to 2L relate to the kinetic energy wave function in the air gap? What does this say about the relationship between wavelength and kinetic energy?

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5) Now let's look at the amplitude of the wave function. What does the amplitude of ψ (or $|\psi|^2$) tell you?

6) If we were to make a measurement of position of the particle, would we be more likely to find it in the region to the left of the air gap or in the air gap (for now ignore the region to the right of the air gap)?

7) In this case of $E > V$, explain how measurements of position for a quantum particle compare to taking a photograph of a classical particle.

PART C: Classical Particle with E < V

Now imagine that the same ball from PART A has an initial total energy of $E = 1.5mgh$, while the height of the hill remains at 2h.

1) What happens to the ball as it starts to go up the hill? Is it possible for the ball to be found between L and 2L? How about between 2L and 3L?

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PART D: Quantum Particle with E < V

1) Now, using the PhET sim, decrease the size of the wire gap to 1 dashed-line wide and increase the height of the potential energy line all the way to the top. What type of function do you see in region 1 and 3 (e.g. sinusoidal, exponential growth, exponential decay, linear, quadratic, etc)?

2) What type of function is shown inside the wire gap (e.g. sinusoidal, exponential decay, exponential growth, linear, etc.)? Hint: It might be more obvious if you look at the wave function when the air gap is very wide… but return to 1 dashed-line wide for the next question!

3) How do the wavelengths of the wave function on the left and right of the air gap compare to each other? What does that tell you about the kinetic energy of the particle in each of those regions?

4) Now refer back to PART C with the classical particle. How does the kinetic energy of the classical particle in regions 2 and 3 compare to the kinetic energy of the quantum particle in regions 2 and 3?

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5) What does the amplitude of ψ (or $|\psi|^2$) tell you about finding a particle in regions 2 or 3?

6) If we were to make a measurement of the particle's position with $E < V$, which region would we be most likely to find it in? Compare this to the case of the classical particle.