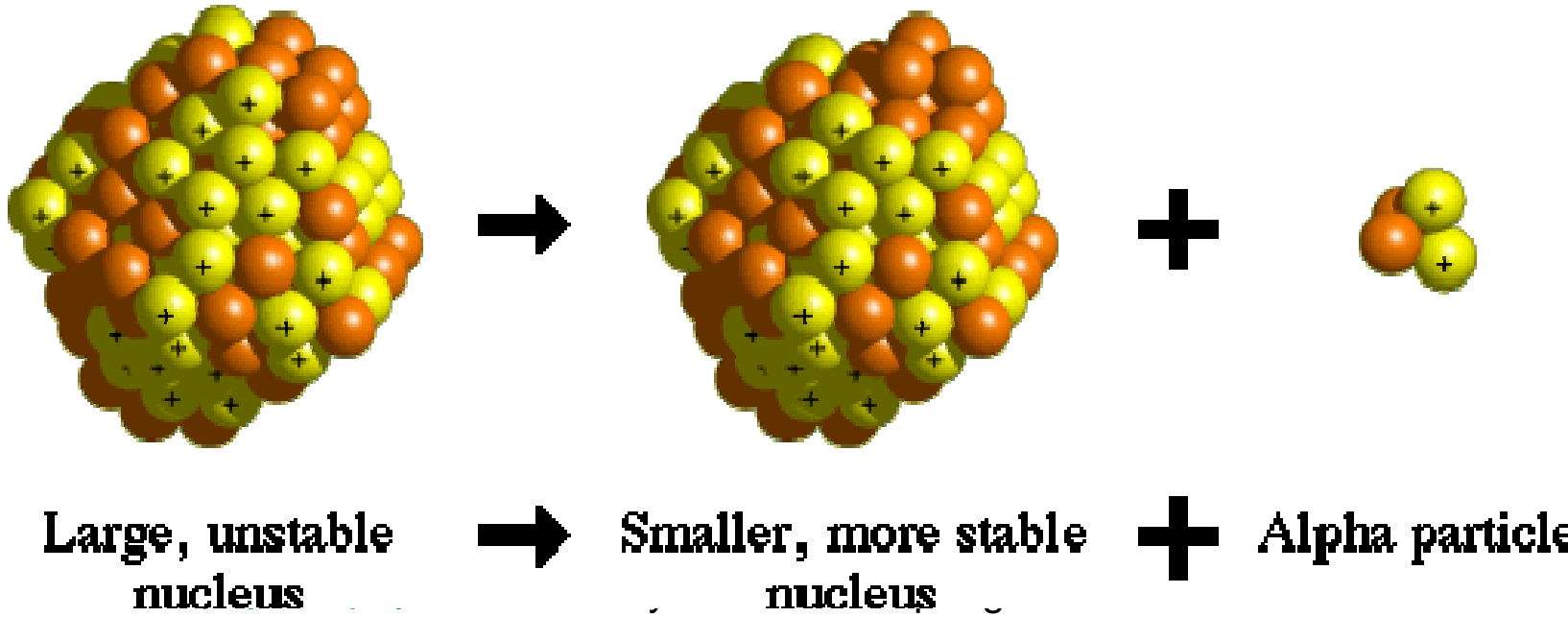


# Quantum tunneling: $\alpha$ -decay

## Announcements:

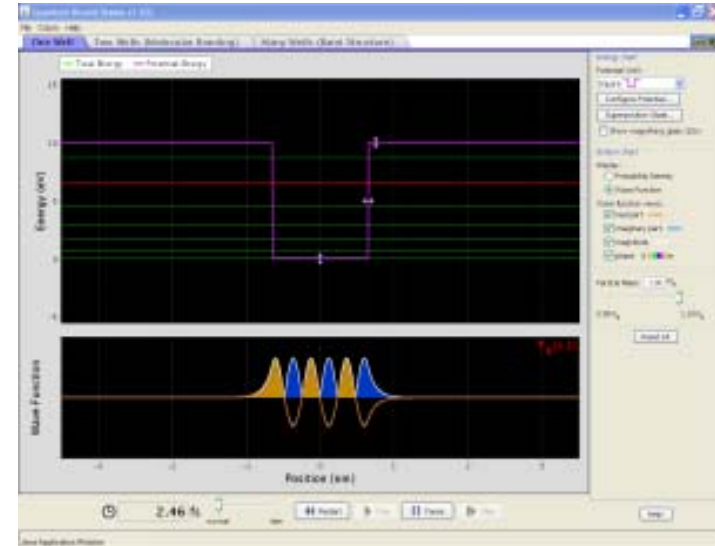
- Exam 2 solutions are posted on CULearn
- Homework solutions will be posted by 7pm tonight
- Next weeks homework will be available by noon tomorrow
- Homework average for set 9 was 36.
- I hope to have the exams graded by class on Friday.



# Quantum bound state simulation

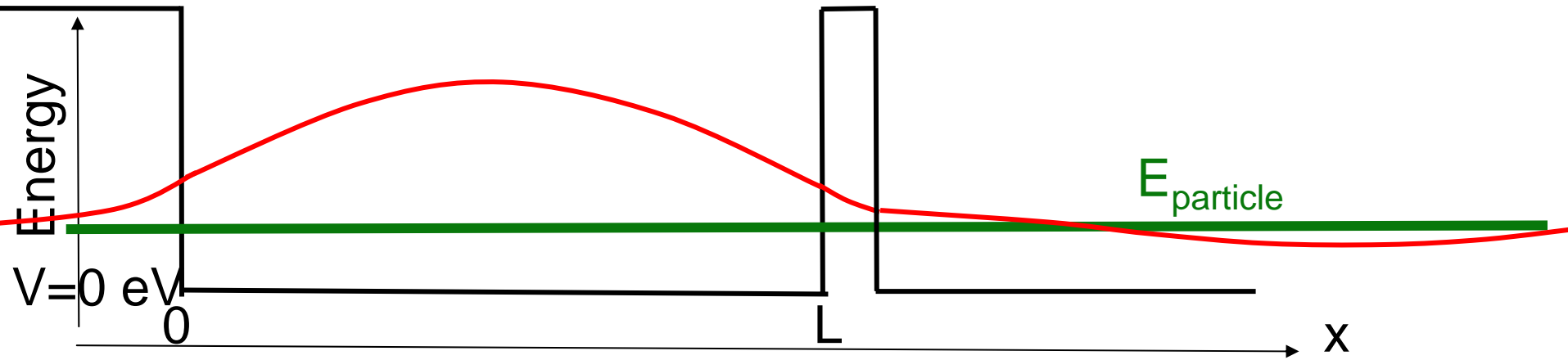
[http://phet.colorado.edu/simulations/sims.php?sim=Quantum\\_Bound\\_States](http://phet.colorado.edu/simulations/sims.php?sim=Quantum_Bound_States)

The quantum bound state simulation can be used to figure out and visualize wave functions and probabilities for various potential curves.



# On to quantum tunneling

The thinner or shorter the barrier, the easier it is to tunnel ...



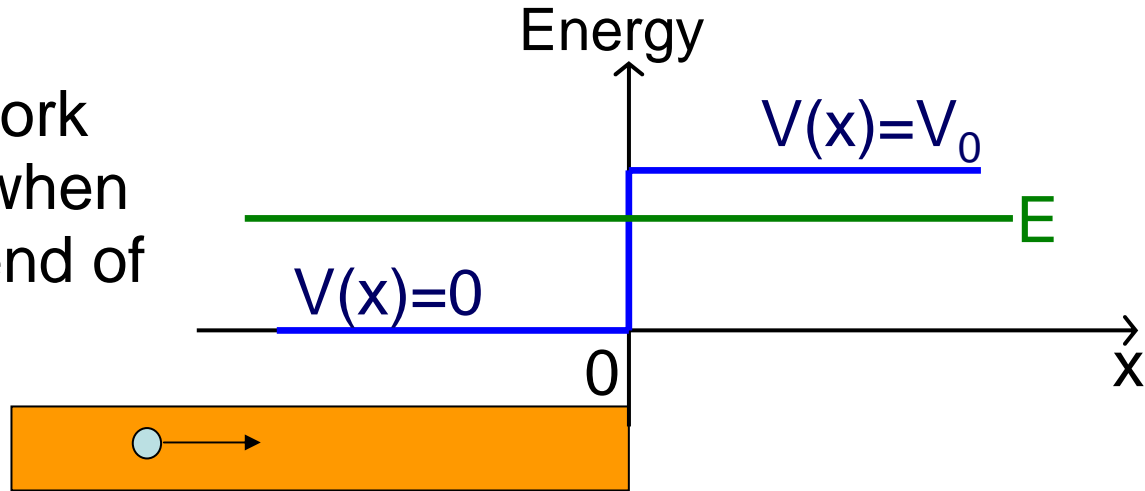
## Examples:

- Electron in wire going through air gap (Tutorial)
- Alpha decay: Explained by Gamow and seen in smoke detectors, radon, space probe power, and assassinations
- Scanning tunneling microscope
- Getting shocked just before touching the door knob

# Clicker question 1

## Set frequency to DA

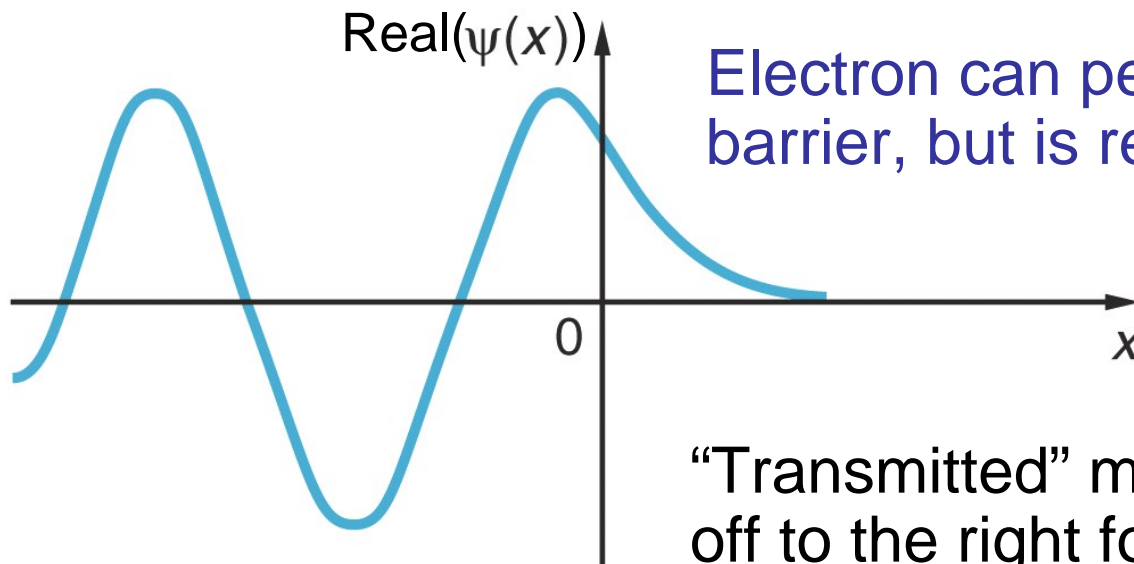
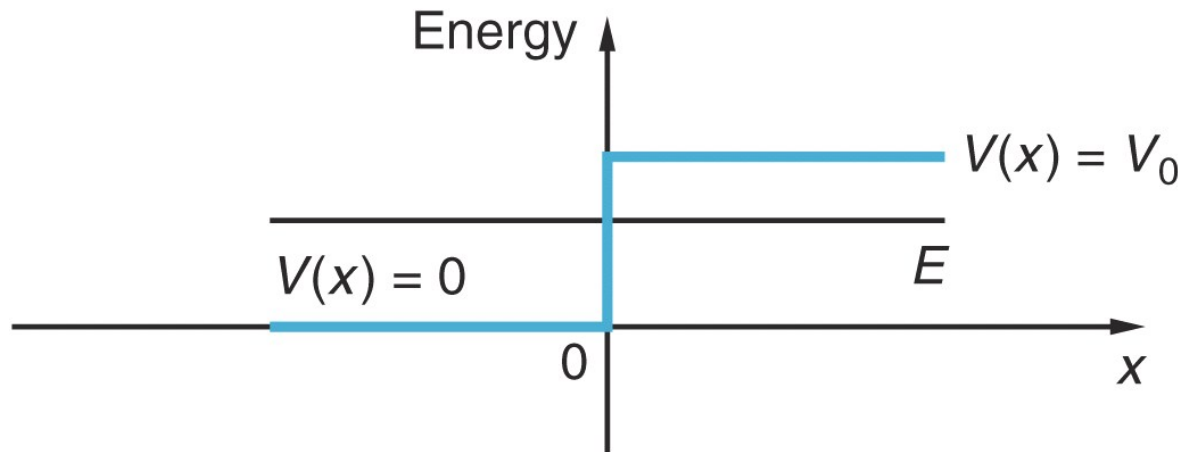
If the total energy  $E$  of the electron is *less* than the work function of the metal,  $V_0$ , when the electron reaches the end of the wire, it will...



- A. stop.
- B. be reflected back.**
- C. exit the wire and keep moving to the right.
- D. either be reflected or transmitted with some probability.
- E. dance around and sing, "I love quantum mechanics!"

Quantum mechanics is not so weird that the electron can keep traveling *forever* with  $E < V_0$ . This scenario is called a potential **step** (the barrier goes on forever).

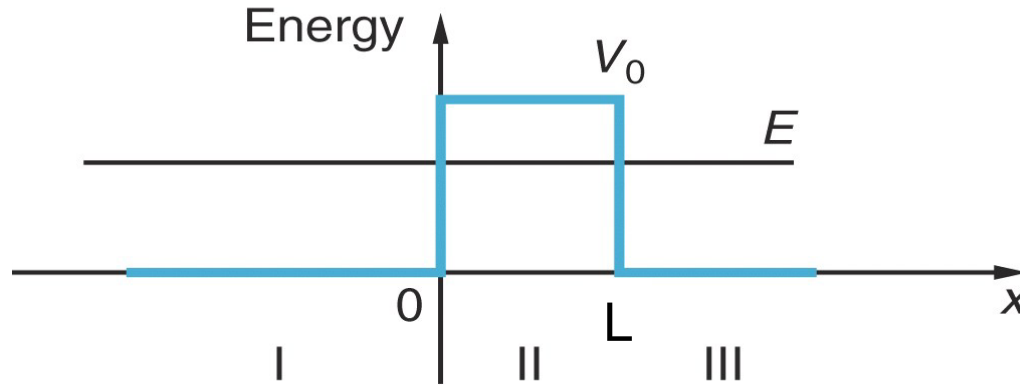
# Electron encounters potential step



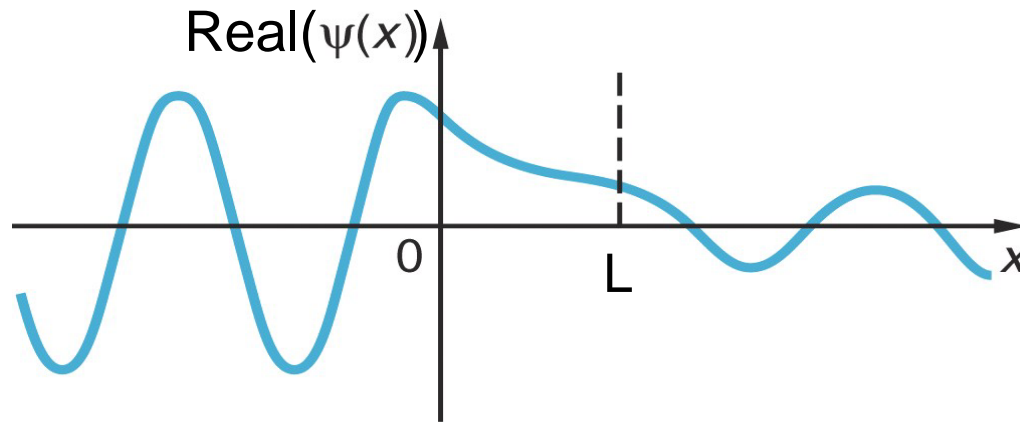
Electron can penetrate into the barrier, but is reflected eventually.

“Transmitted” means continues off to the right forever, i.e. the wave function does not go down to zero.

# Quantum tunneling



If the potential increase has a finite width, it is a potential *barrier* and the electron can tunnel out of Region I



This is what you were encouraged to derive in the tutorial

Copper wire #1

CuO

Copper wire #2



# Quantum tunneling probability

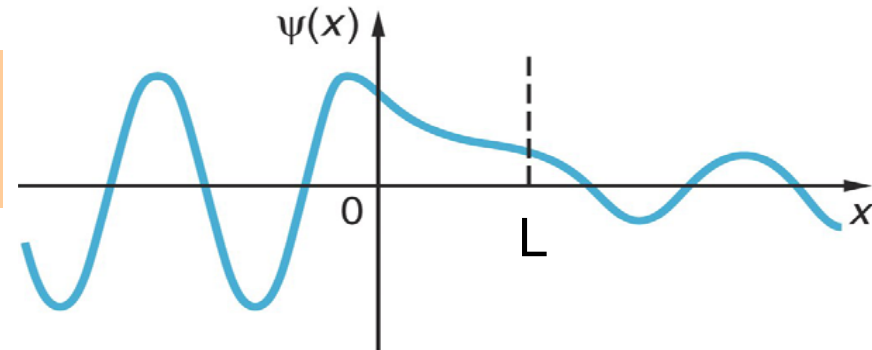
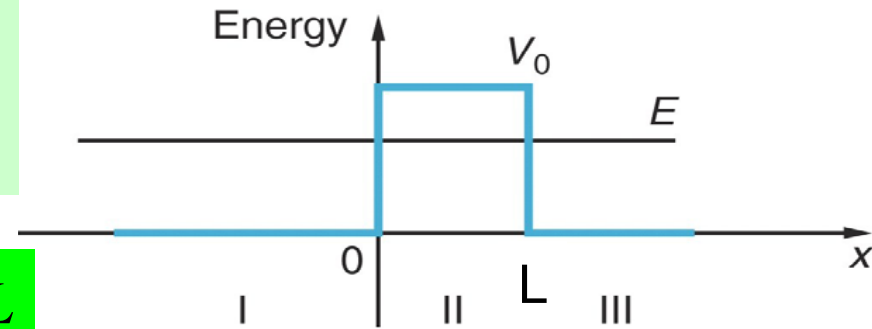
The probability of tunneling depends on two parameters:

1. The parameter  $\alpha$  measures how quickly the exponential decays and  $\lambda=1/\alpha$  is the penetration depth (how far the wave function penetrates).

$$\alpha = \frac{\sqrt{2m(V - E)}}{\hbar}$$

2. The width of the barrier  $L$  measures how far the particles has to travel to get to the other side.

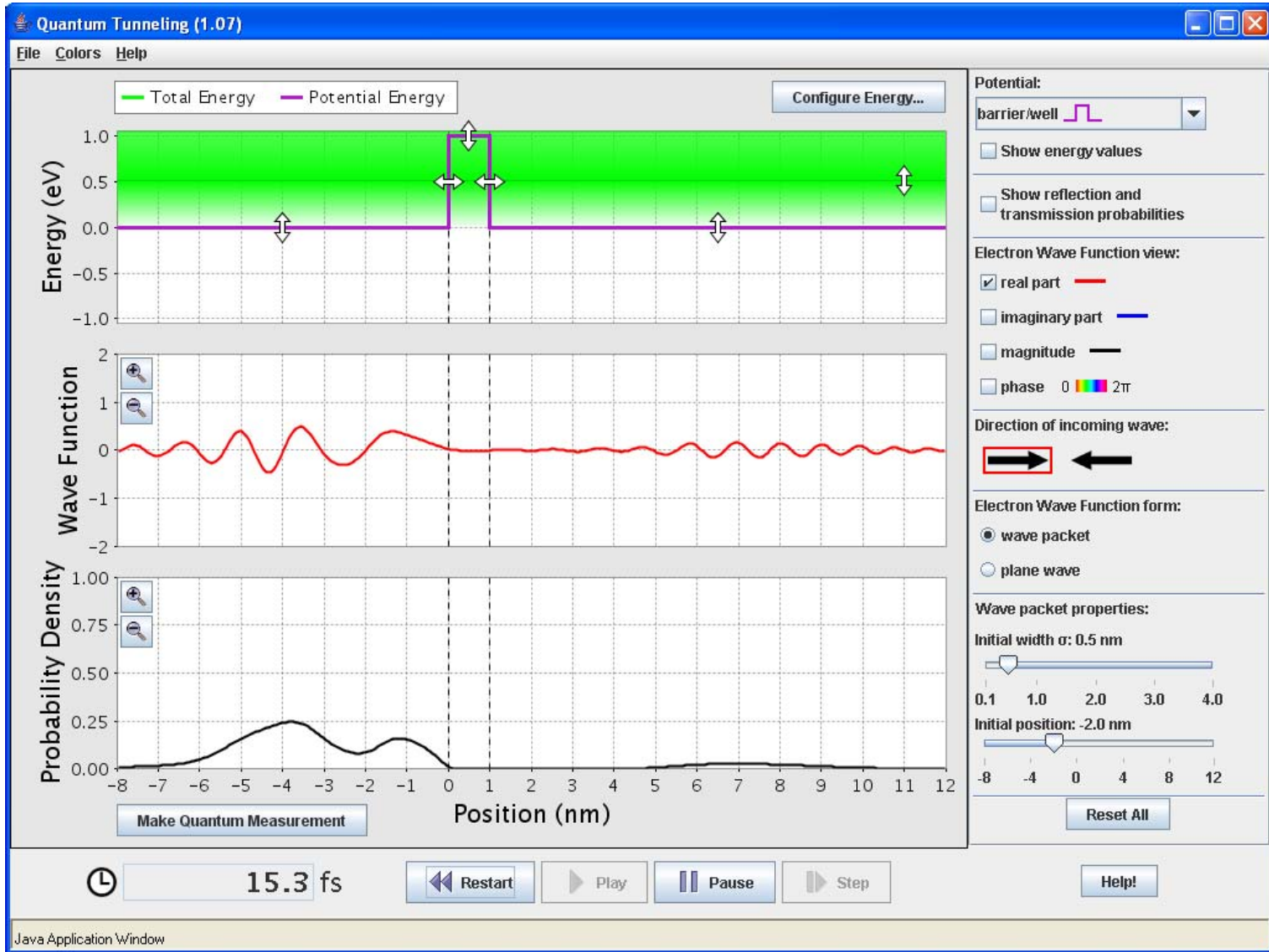
The quantum tunneling probability is  $P \approx e^{-2\alpha L}$



As  $\alpha$  increases (penetration depth decreases), probability decreases.

As  $L$  increases (barrier width increases), probability decreases.

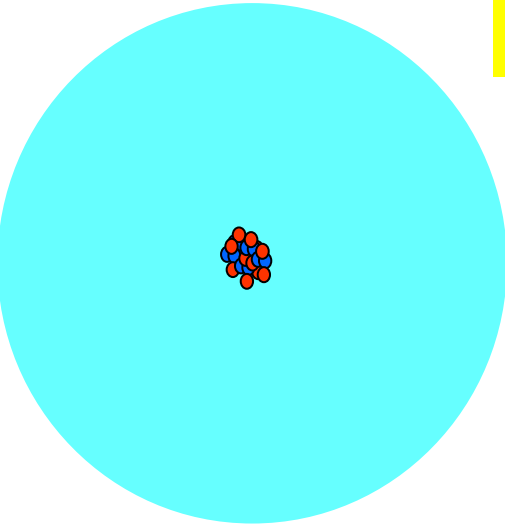
# Quantum Tunneling Sim



# Radioactive decay

Radon-222:  
86 protons,  
136 neutrons

- Proton (**positive charge**)
- Neutron (**no charge**)



Two competing forces act inside the nucleus:

**Coulomb force:** Protons have the same charge and are very close together so there is a large repulsion from the Coulomb force.

**Nuclear force:** Protons and neutrons feel the *strong force* which is a very strong **attractive** force but very short range.

Nuclei with many protons and neutrons are generally unstable.

One type of radioactive decay is called alpha decay which releases an  $\alpha$  particle)

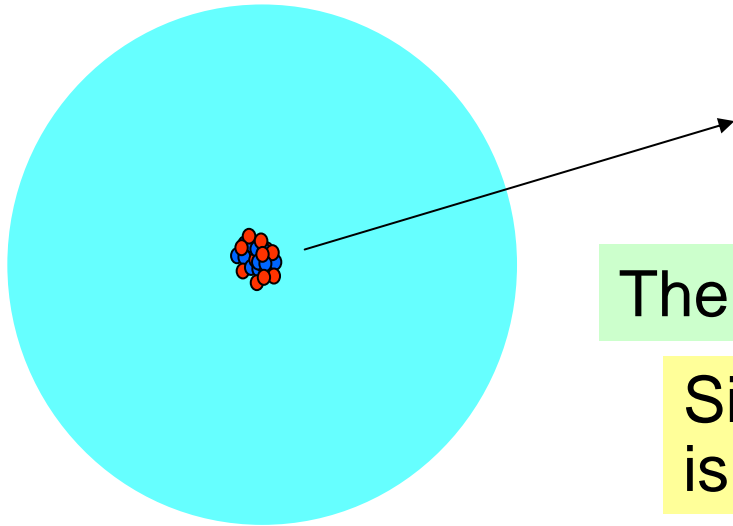
Alpha particle is 2 neutrons  
+ 2 protons (Helium nucleus)



# Radioactive decay

- Proton (**positive charge**)
- Neutron (**no charge**)

Radon-222  
86 protons,  
136 neutrons



In alpha-decay,  
an alpha-particle  
is emitted from  
the nucleus.

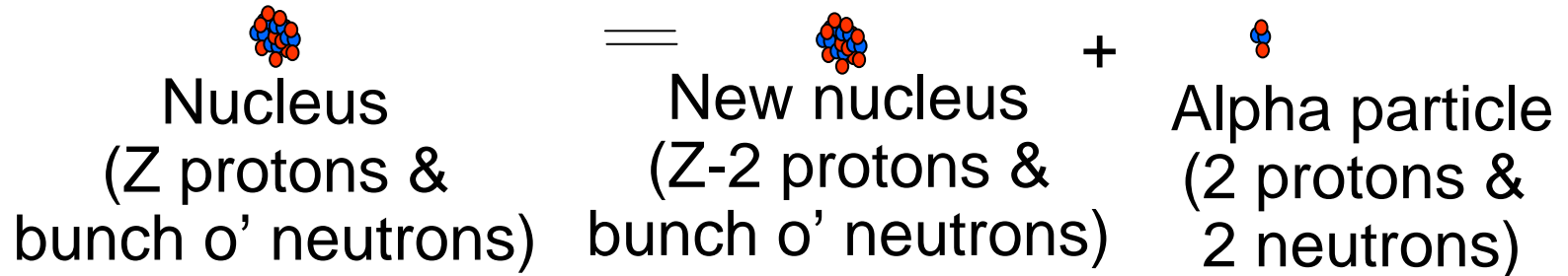
The raises the ratio of neutrons to protons

Since neutrons are neutral, there  
is no Coulomb repulsion.

Thus, increasing the neutron to proton  
ratio makes a more stable nucleus.

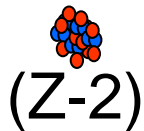
# Analyzing alpha decay

Starting point *always* to look at potential energy curve for particle



Look at this system as the distance between the alpha particle and the nucleus changes.

As we bring the  $\alpha$  particle closer, what happens to the potential energy? Answering this question will help us figure out the potential energy curve.



Far away,  $V=0$

# Clicker question 2

# Set frequency to DA

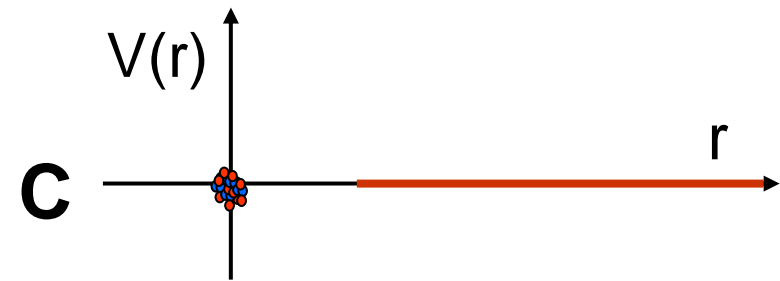
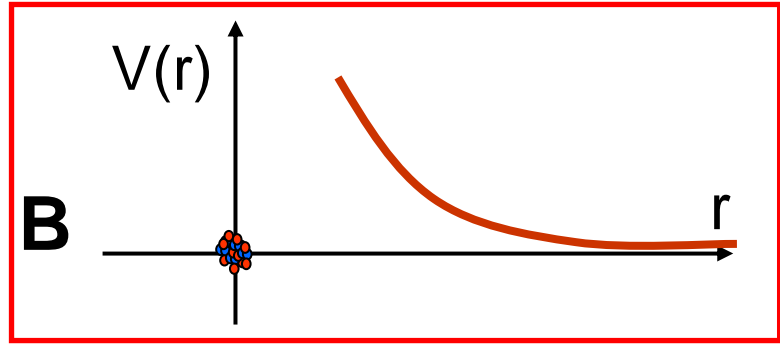
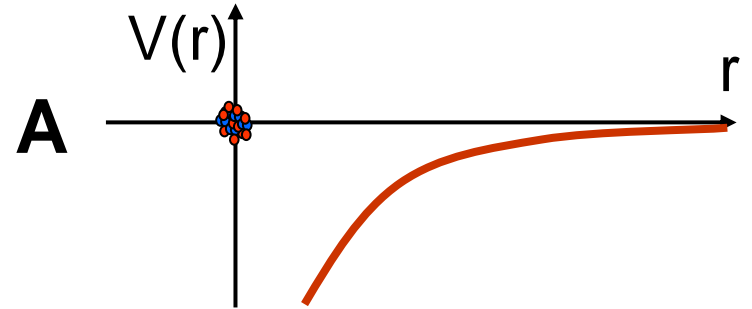


← Far away,  $V=0$

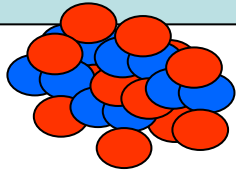
As  $\alpha$  particle gets closer, what happens to the potential energy? Which is the best representation of the potential energy?

$$V(r) = \frac{kq_1q_2}{r} = \frac{k(\overbrace{Z-2}^{\text{nucleus}})(\overbrace{e}^{\alpha})(2e)}{r}$$

Takes energy to push positively charged  $\alpha$  towards positively charged nucleus, so potential energy must increase.



**D.** Something else



← Bring alpha-particle closer

