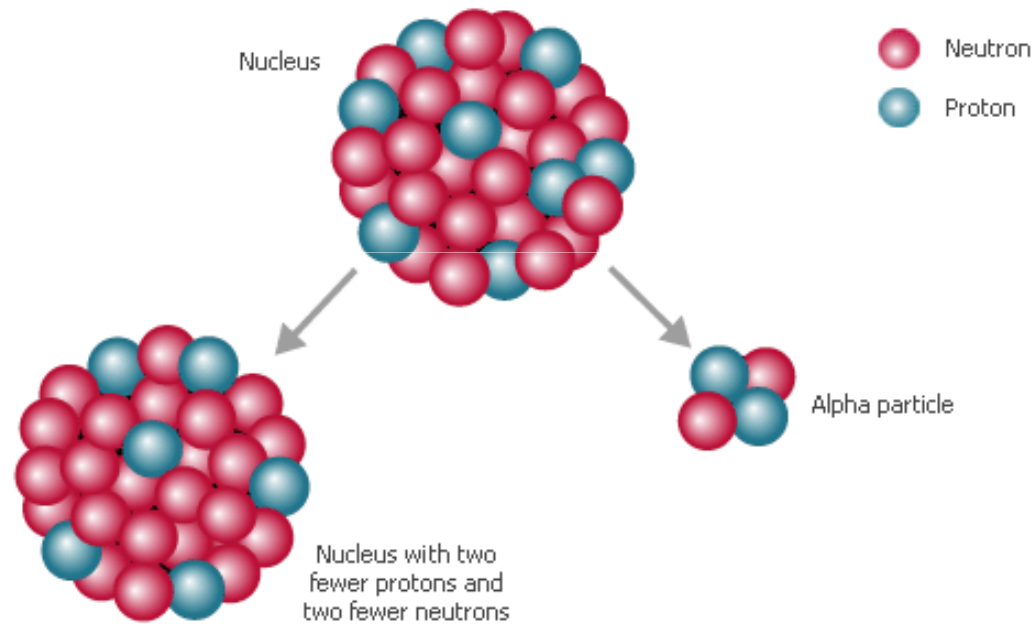


# Alpha Decay and Nuclear Weapons/Energy



Phys 2130, Day 33:

Questions?

Alpha Decay

# Review: Quantum Tunneling

Quantum tunneling probability

$$P \approx e^{-2\alpha D}$$

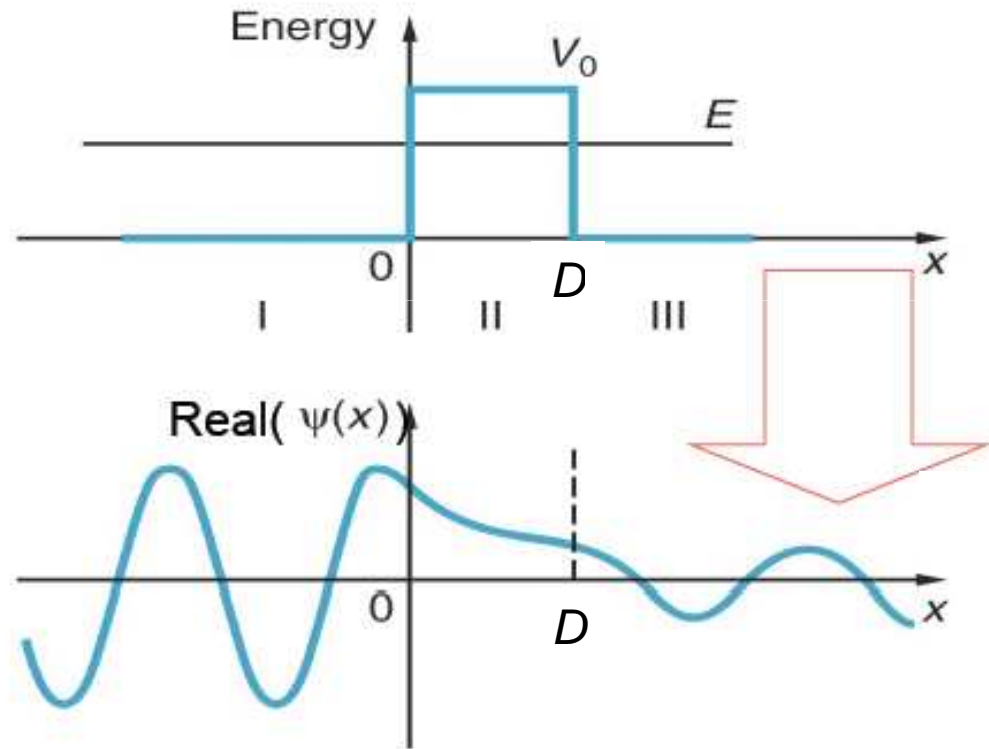
depends on

- Parameter  $\alpha$

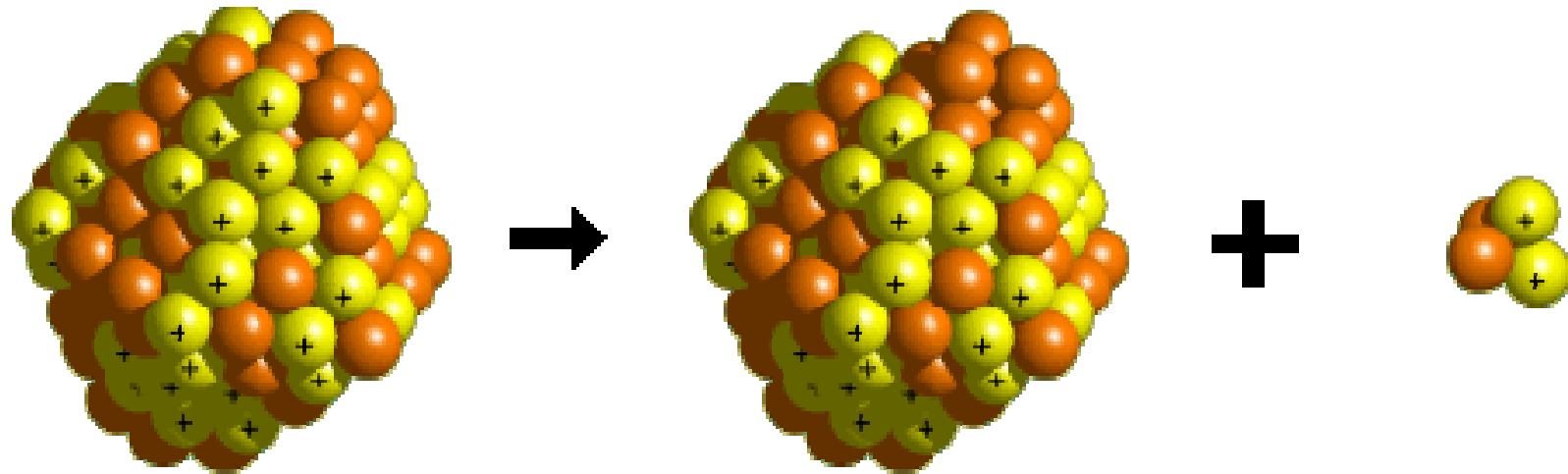
$$\alpha = \frac{\sqrt{2m(V - E)}}{\hbar}$$

( $\lambda=1/\alpha$ : penetration depth)

- Width of barrier  $D$



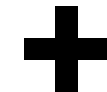
# Quantum Tunneling: $\alpha$ -decay



**Large, unstable  
nucleus**



**Smaller, more stable  
nucleus**



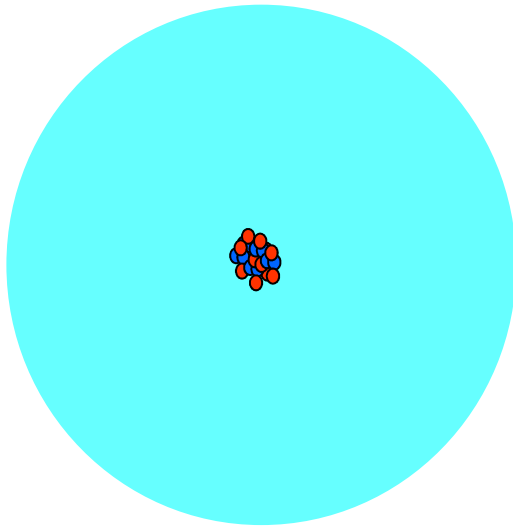
**Alpha particle**

Atoms having nuclei with many protons and neutrons are generally unstable  $\rightarrow$  emit a particle

One type of radioactive decay is called alpha decay which releases an alpha particle (consists of 2 protons and 2 neutrons)

# Alpha decay

Radon-222  
86 protons,  
136 neutrons



## Two competing forces act inside nucleus

### Coulomb force

Protons have same charge and really close together, so very big *repulsion* from Coulomb force

### Nuclear force

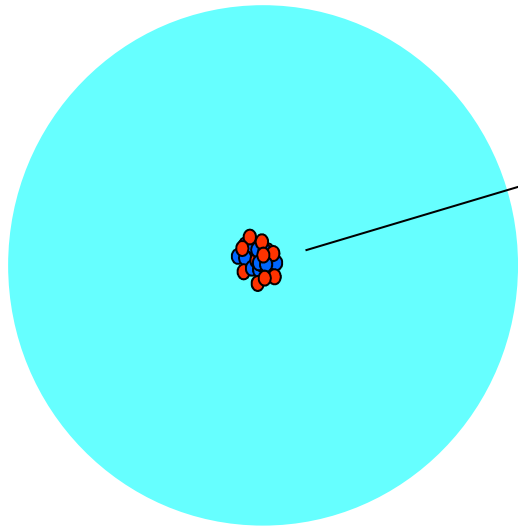
Particles inside the nucleus feel the STRONG force which is very strong *attractive* force but has a very short range only

# Alpha decay

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

Radon-222  
86 protons,  
136 neutrons

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



This raises the ratio of neutrons to protons

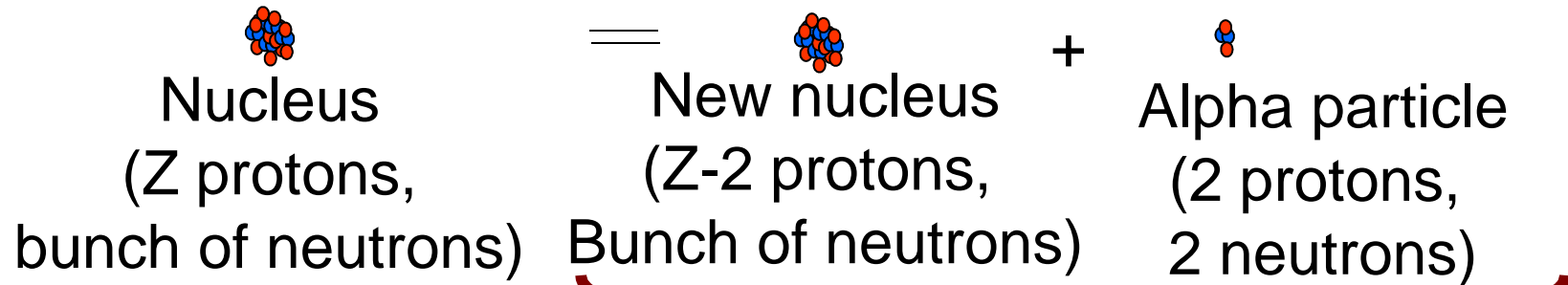
Neutrons are neutral ... no Coulomb repulsion, but strong (nuclear) force attraction

Thus, increasing the ration of neutrons to protons makes for a more stable nucleus (atom)

# Analyzing alpha decay

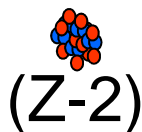
How does this happen?

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  $\alpha$  closer,  
what happens to potential energy?



$V=0$

At a great distance

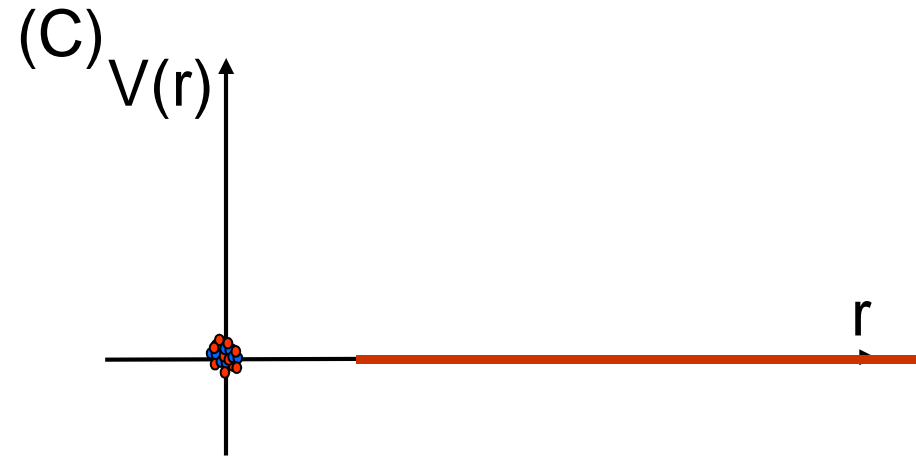
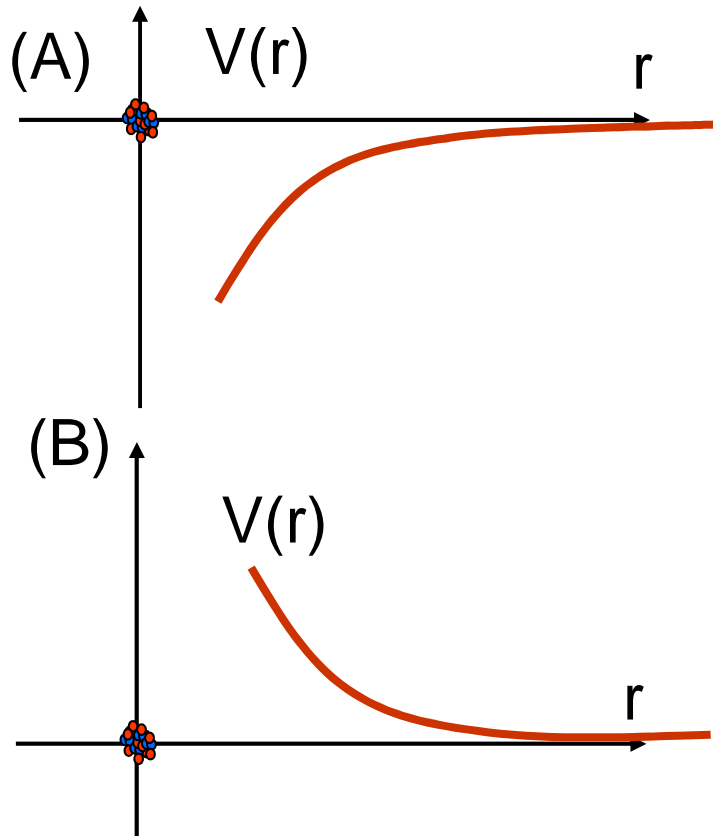


# Analyzing alpha decay

As we bring  $\alpha$  closer, what happens to potential energy?

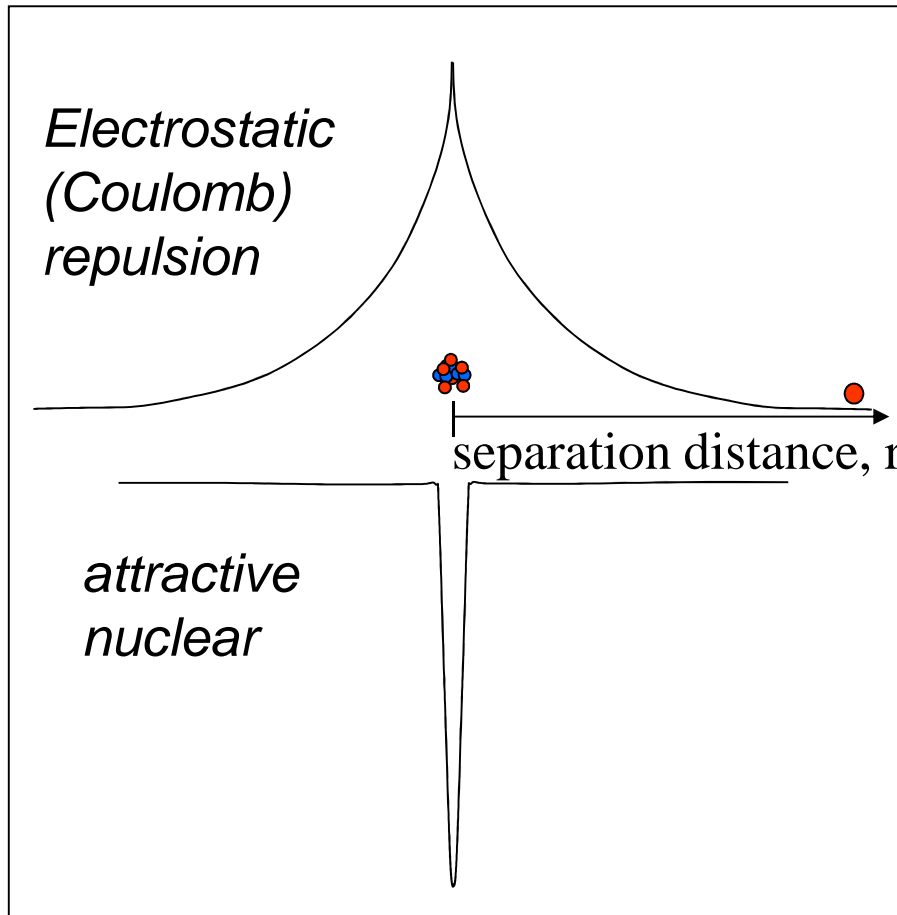


  $V=0$  at a great distance 

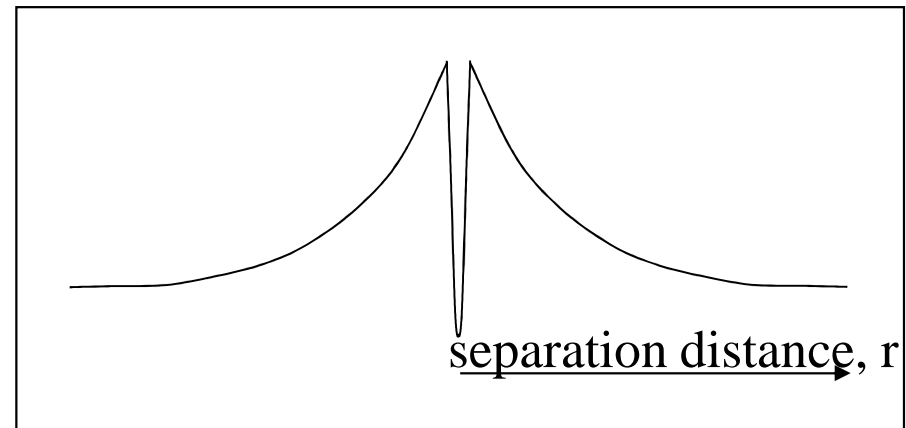


(D) Something else

# Potential energy curve for alpha decay

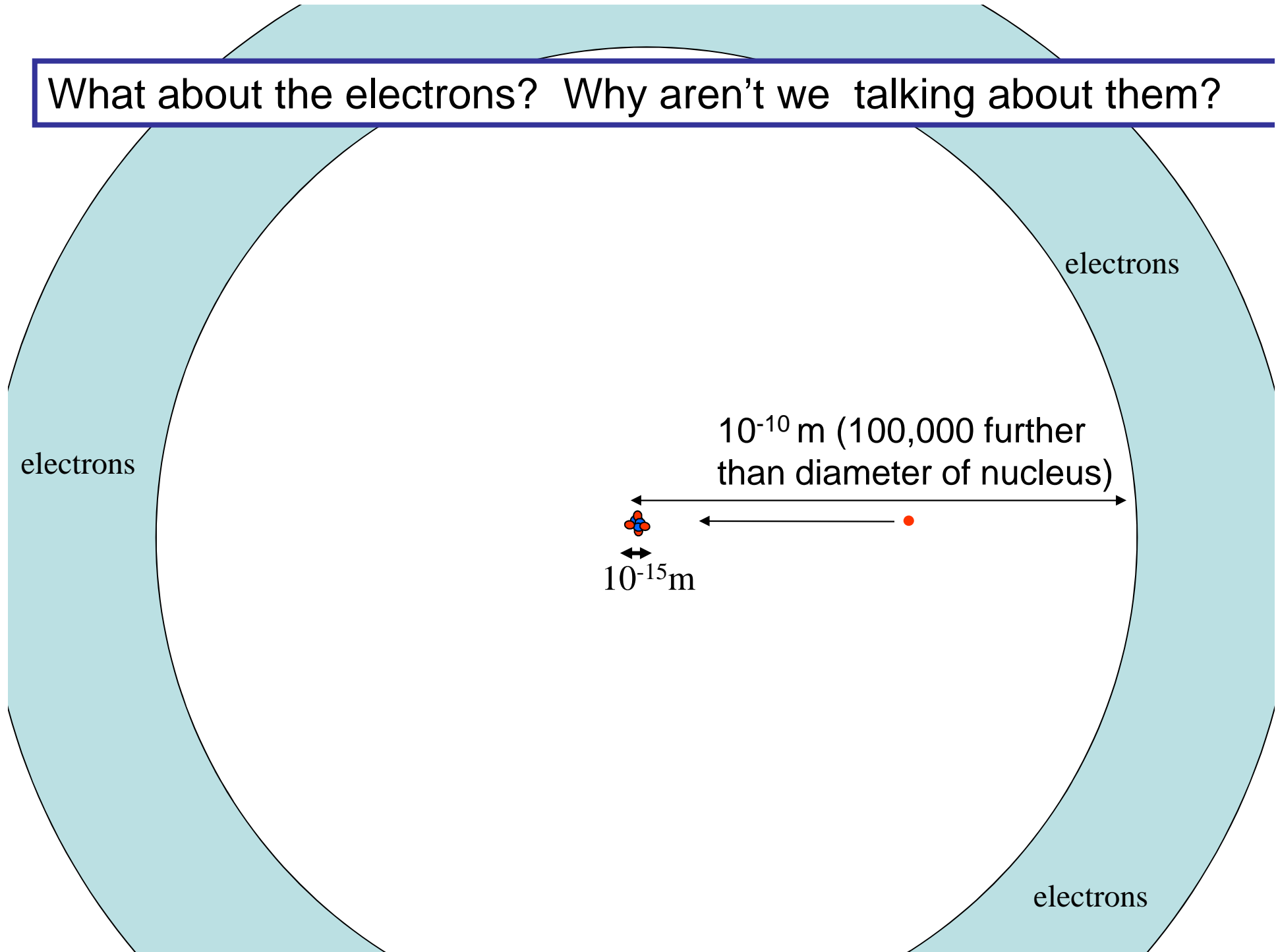


## Superposition - real nucleus





What about the electrons? Why aren't we talking about them?



# Energy scales

Nuclear energy scale (holding nuclei together) gigantic as compared to chemical energy (holding molecules together).

Why? Simply, Coulomb's law.

$$F = \frac{k (\text{charge of \#1})(\text{charge of \#2})}{r^2}$$

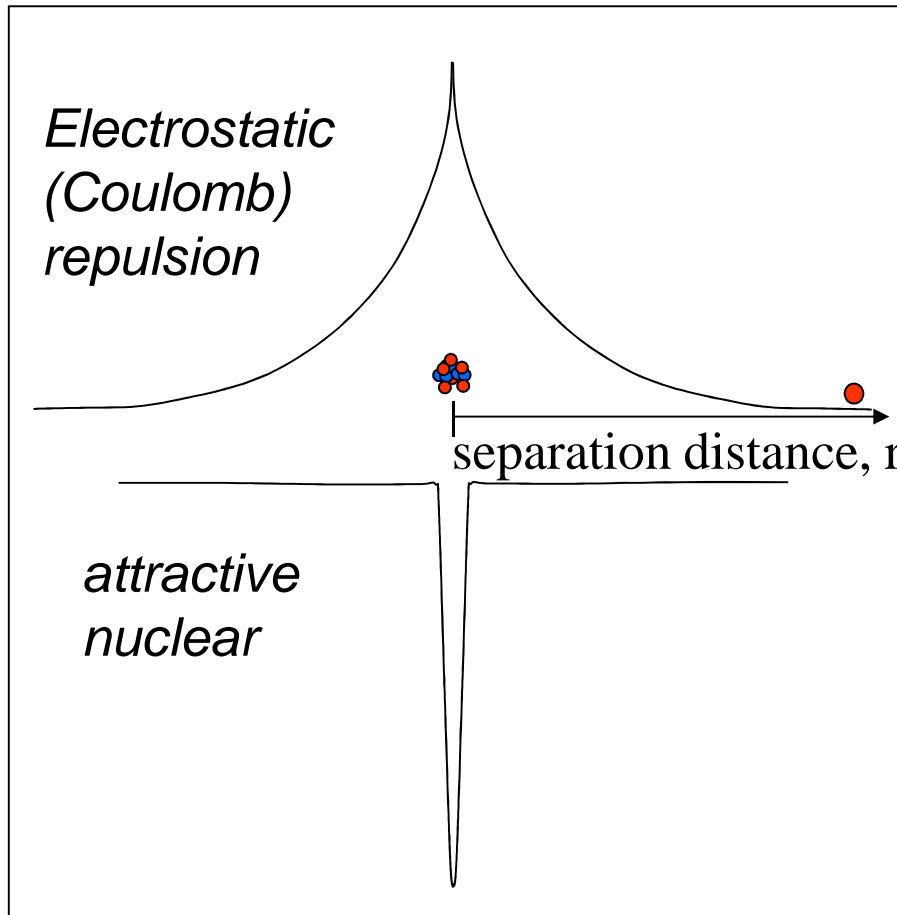
**Chemistry** - forces between electrons and protons on distance scale of atomic size ( $> 10^{-10}$  m).

**Nuclear forces** - forces between protons on distance scale 10-100,000 times smaller.

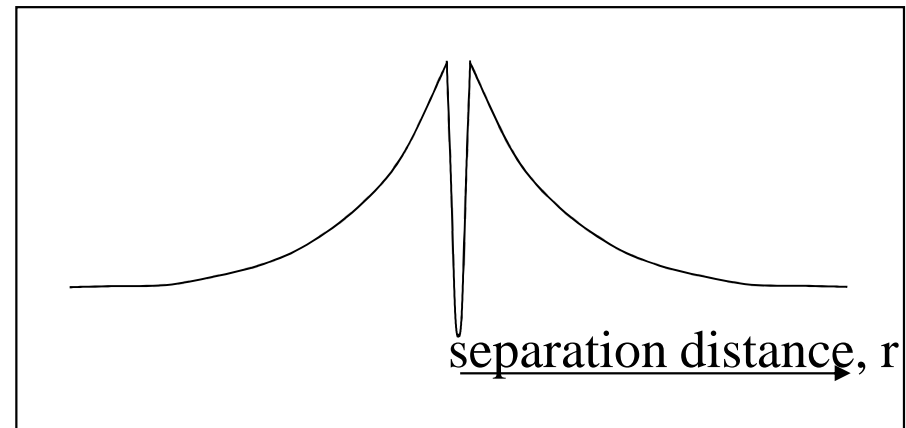
10,000 times closer means forces **100,000,000 times bigger** because of  $1/r^2$ . Lots more potential energy stored !!!

Conclusion: Conventional (chemical interaction) weapons are so much less powerful than nuclear weapons?

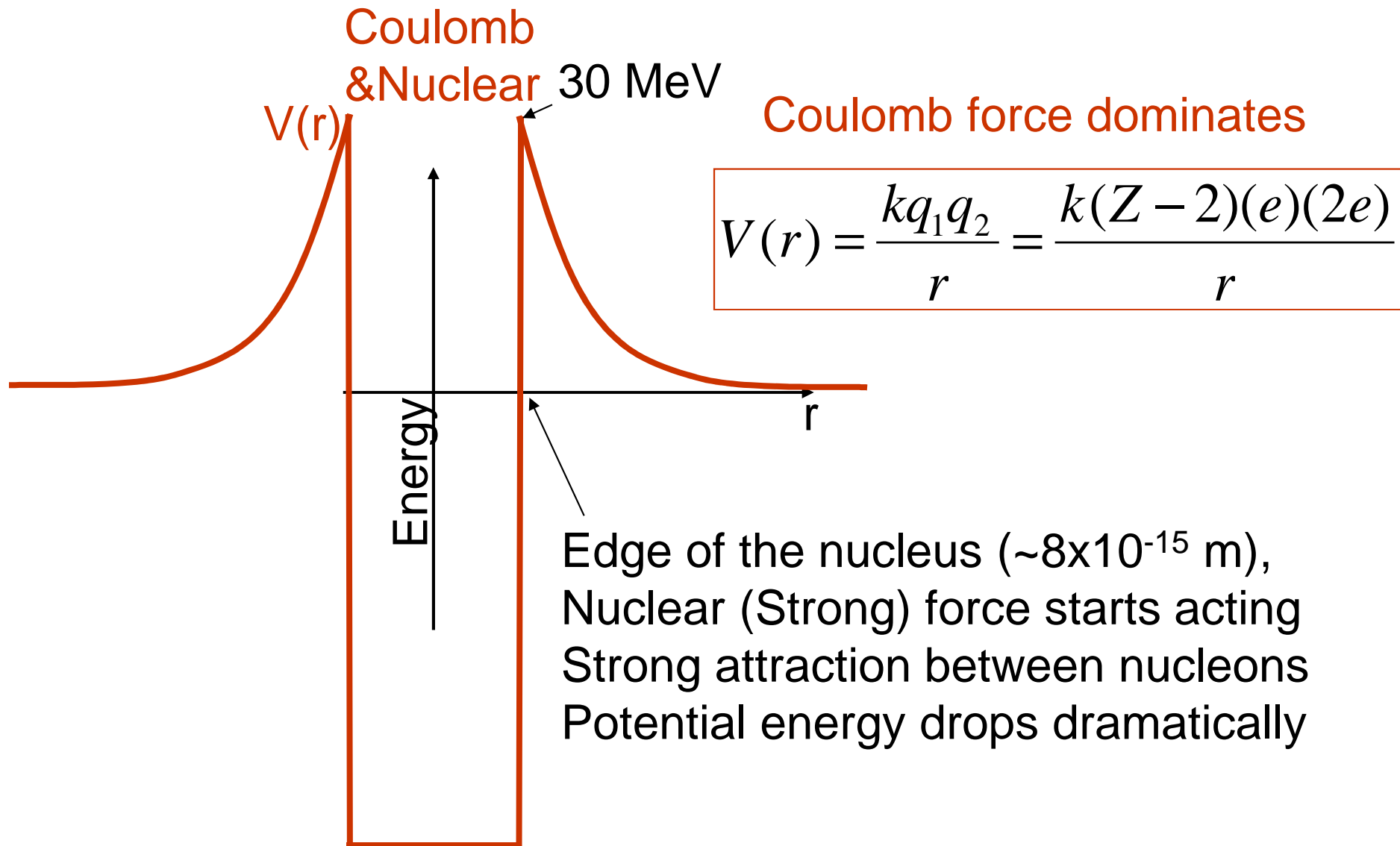
# Potential energy curve for alpha decay



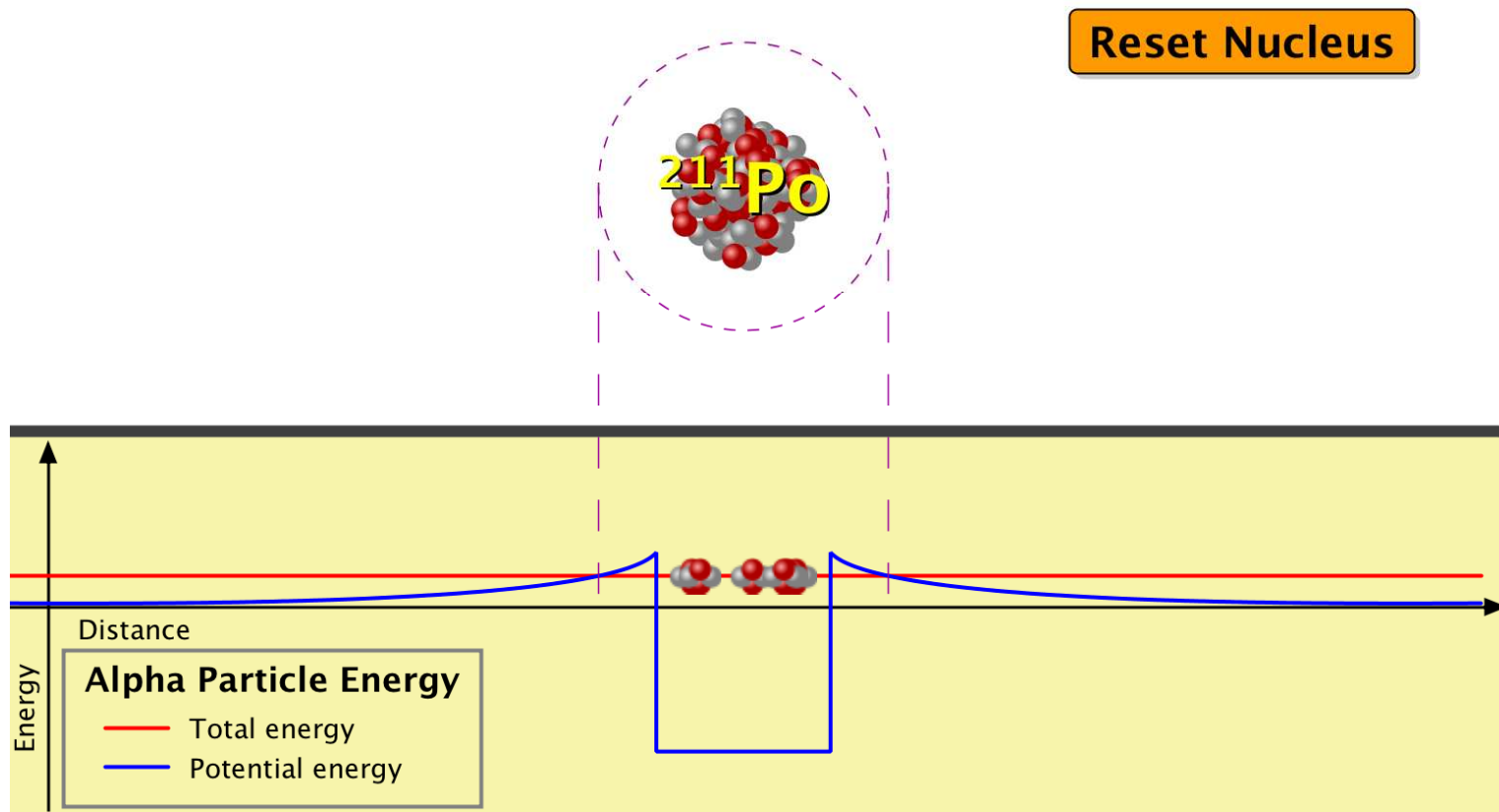
## Superposition - real nucleus



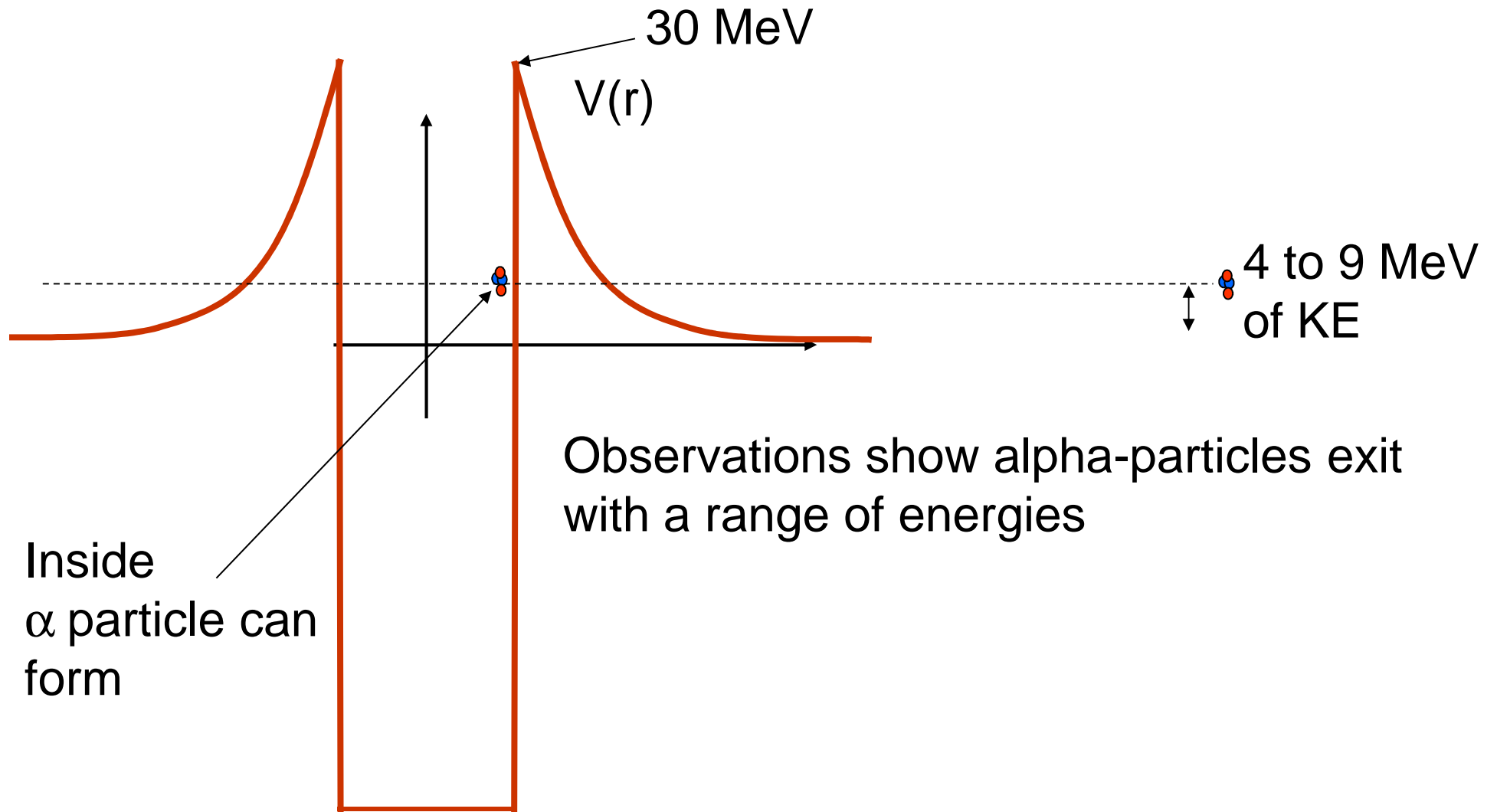
# Potential energy curve for alpha decay (simplified for further analysis)



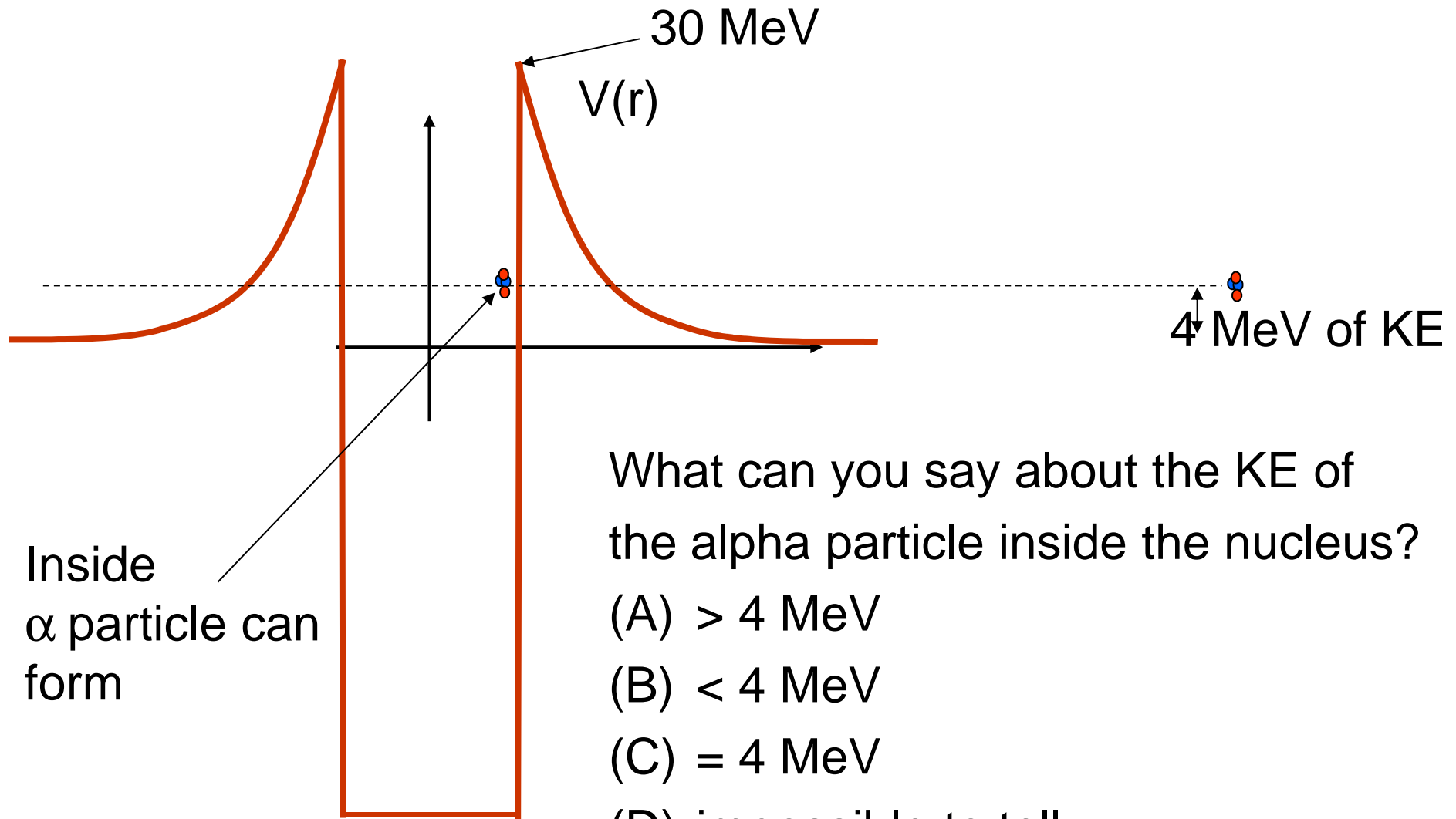
# Alpha Decay Sim



# Quantum Tunneling: $\alpha$ -decay



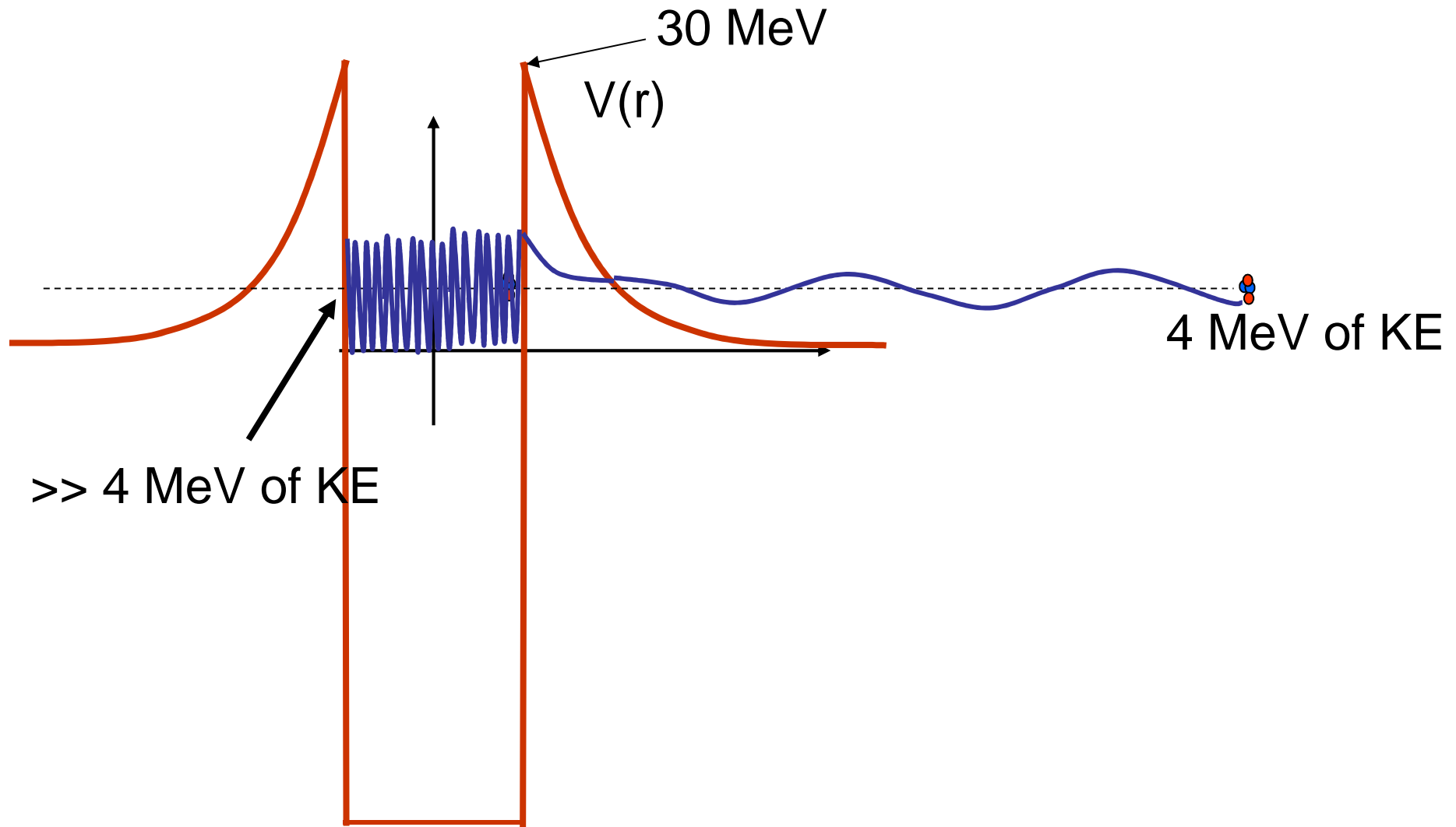
# Quantum Tunneling: $\alpha$ -decay



What can you say about the KE of the alpha particle inside the nucleus?

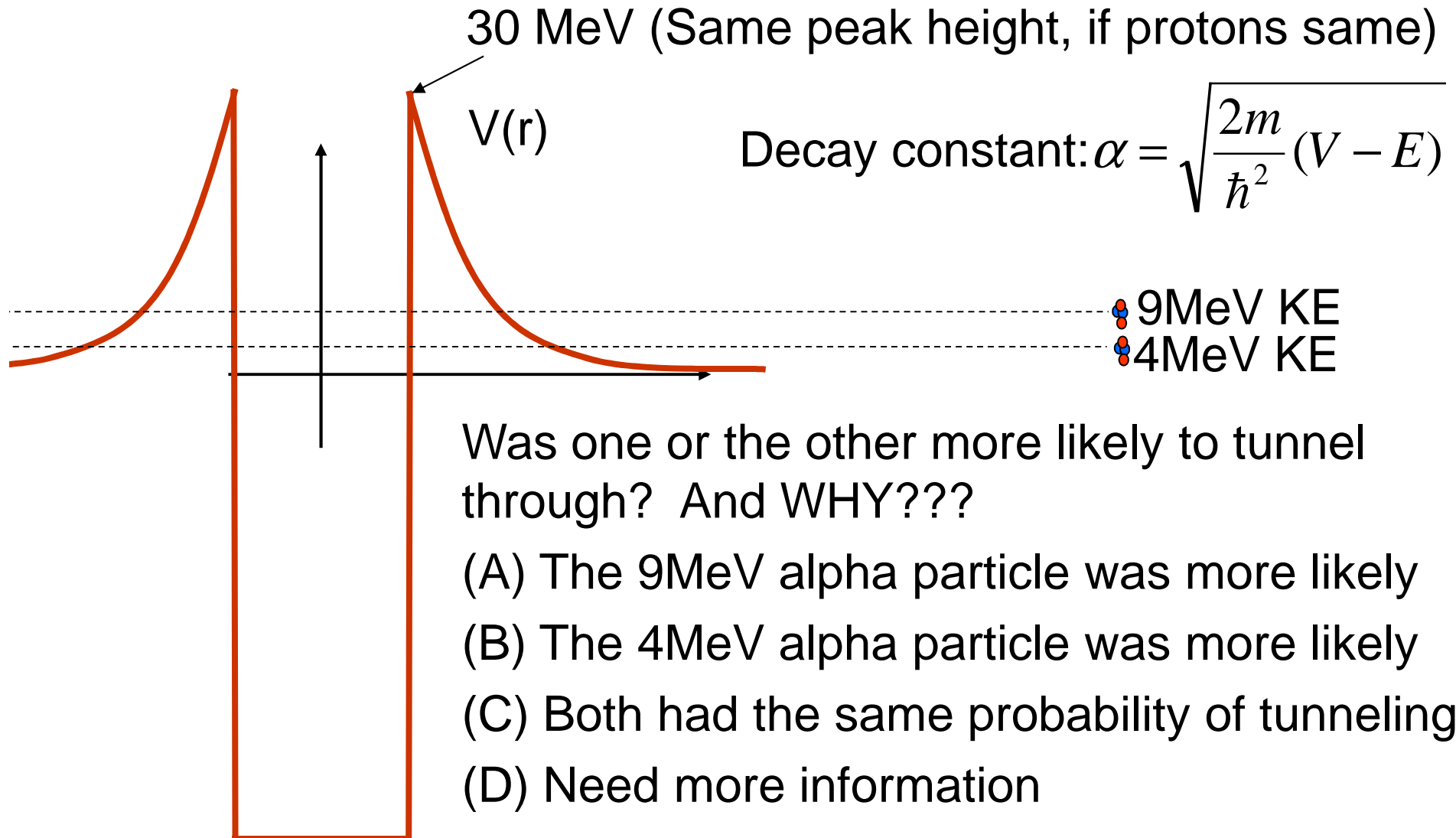
- (A)  $> 4$  MeV
- (B)  $< 4$  MeV
- (C)  $= 4$  MeV
- (D) impossible to tell

# Quantum Tunneling: $\alpha$ -decay

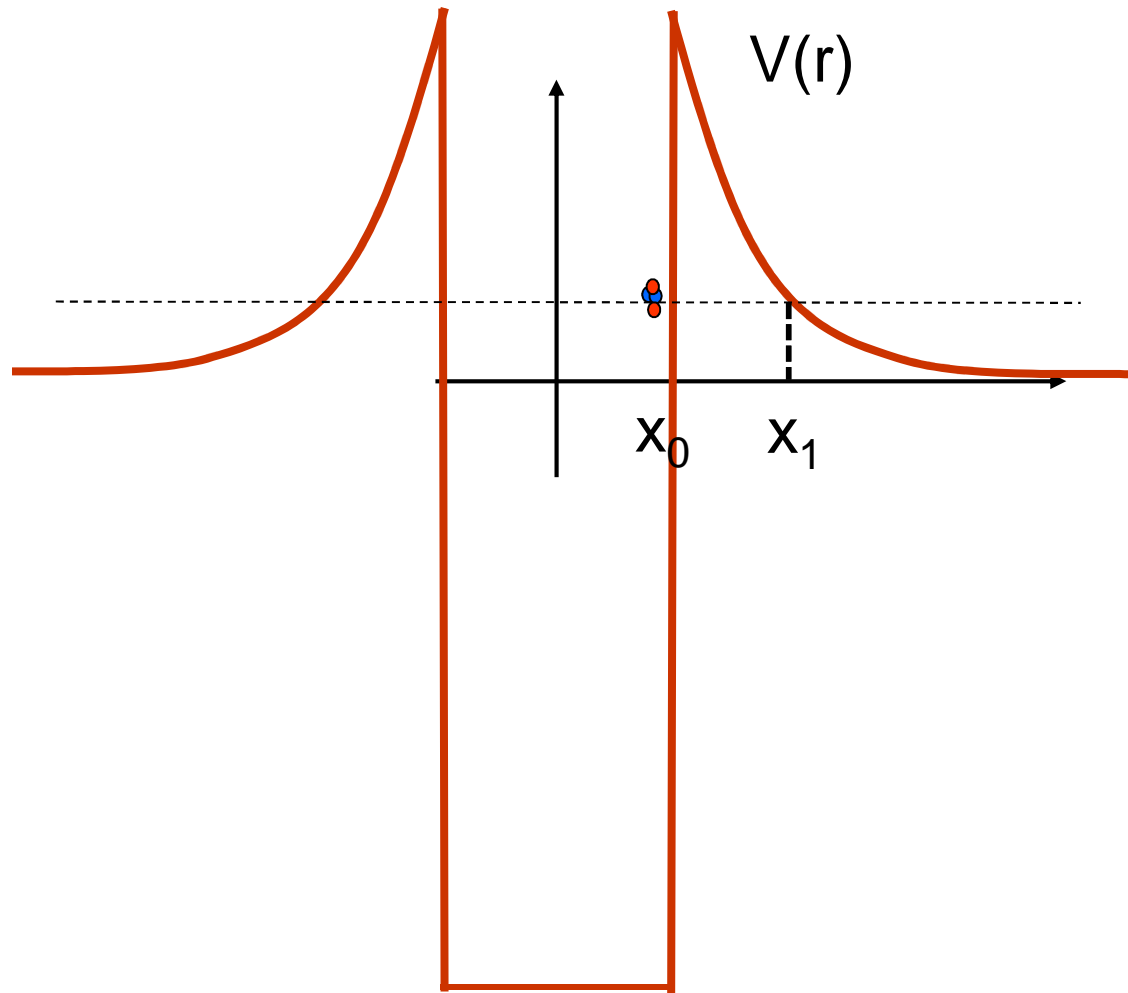




Observe  $\alpha$ -particles from different isotopes (same protons, different neutrons), exit with different amounts of energy.



# Quantum Tunneling: $\alpha$ -decay



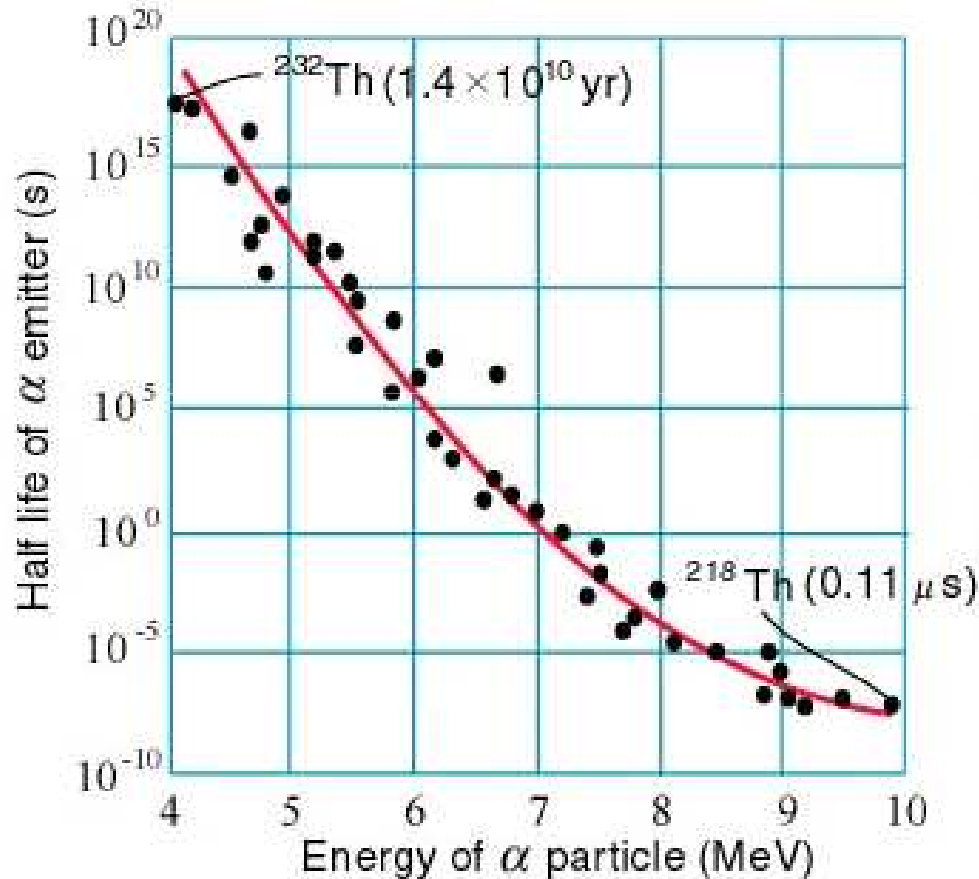
For square well:

$$P \approx e^{-2\alpha D}$$

For our alpha-decay model potential:

$$P \approx e^{-\int_{x_0}^{x_1} 2\alpha x dx}$$

# Lifetimes of unstable nuclei



Lifetimes vary by orders of magnitude:

$$E = 4 \text{ MeV} \rightarrow 10^{23} \text{ s}$$

$$E = 6 \text{ MeV} \rightarrow 10^8 \text{ s}$$

$$E = 9 \text{ MeV} \rightarrow 10^{-4} \text{ s}$$

Was hard to understand how one common process could lead to such different lifetimes

Huge success of model !