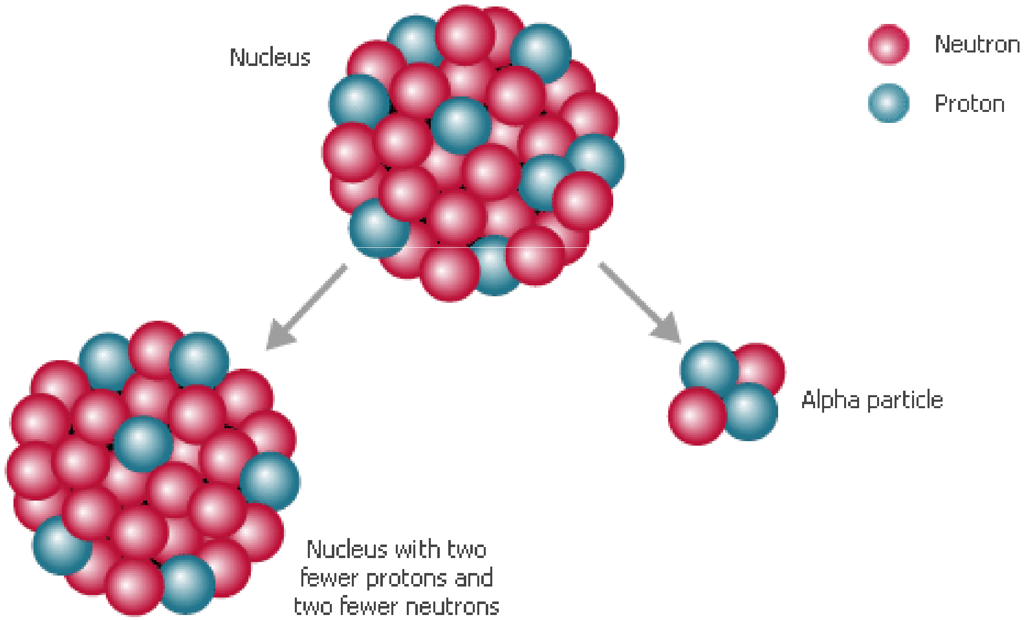
Alpha Decay and Nuclear Weapons/Energy



Phys 2130, Day 33:
Questions?
Alpha Decay

Review: Quantum Tunneling

Quantum tunneling probability

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

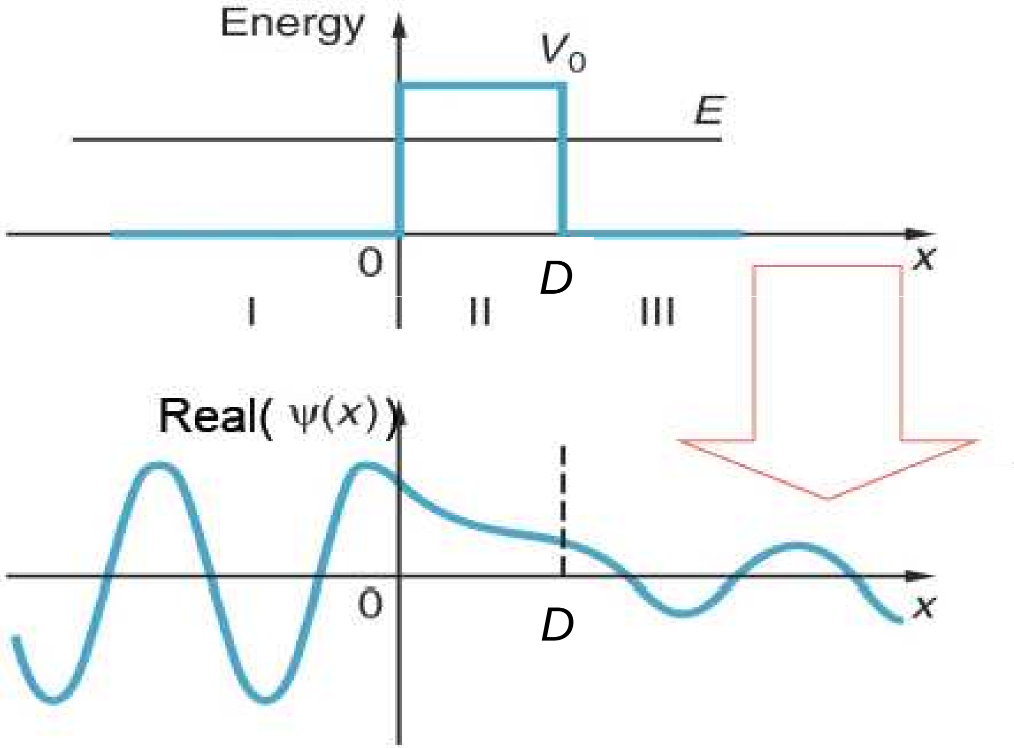
depends on

- Parameter α

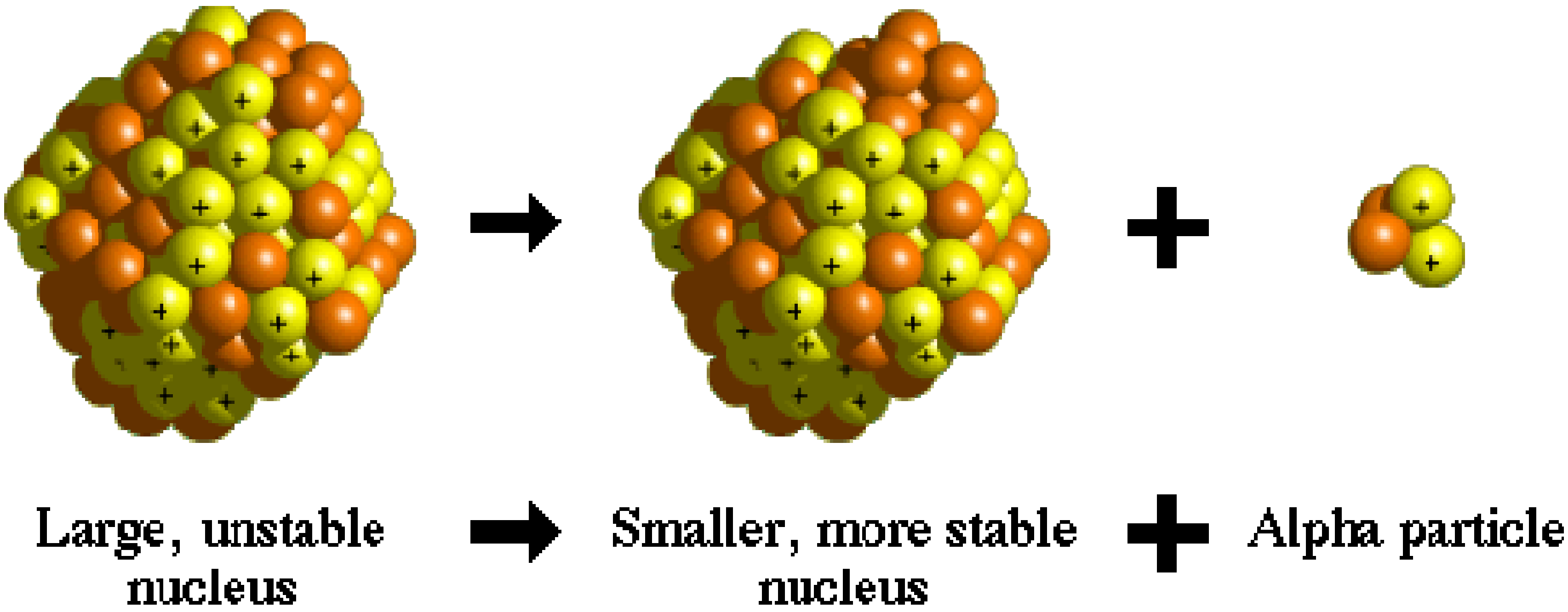
$$\alpha = \frac{\sqrt{2m(V-E)}}{\hbar}$$

(λ=1/α: penetration depth)

- Width of barrier *D*



Quantum Tunneling: α-decay

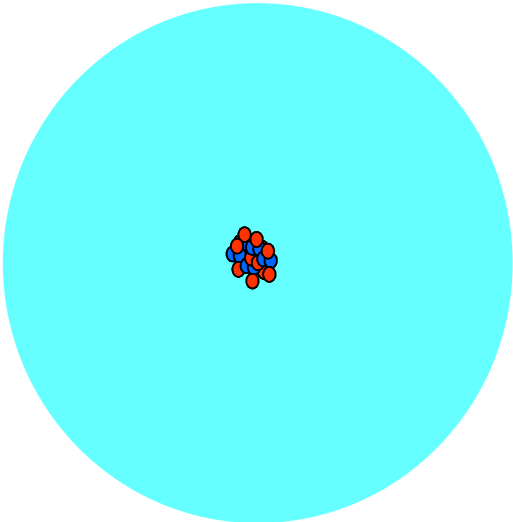


Atoms having nuclei with many protons and neutrons are generally unstable → emit a particle

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

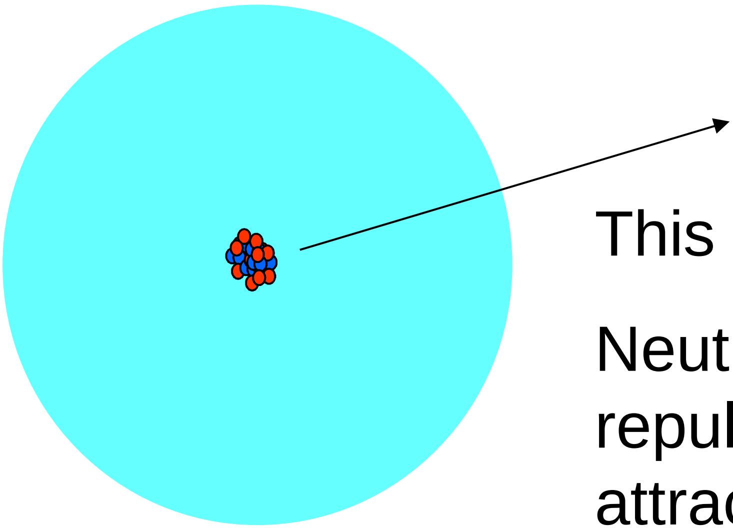
Particles inside the nucleus feel the STRONG force which is very strong ***attractive*** force but has a very short range only

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

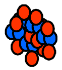
Neutrons are neutral … no Coulomb repulsion, but strong (nuclear) force attraction

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

Analyzing alpha decay

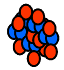
How does this happen?

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



Nucleus
(Z protons,
bunch of neutrons)

=



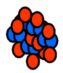
New nucleus
(Z-2 protons,
Bunch of neutrons)

+

Alpha particle
(2 protons,
2 neutrons)

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

As we bring α closer,
what happens to potential energy?

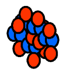


(Z-2)

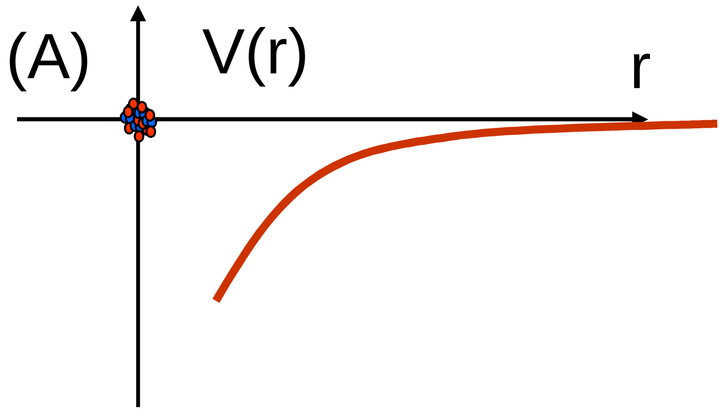
V=0
At a great distance

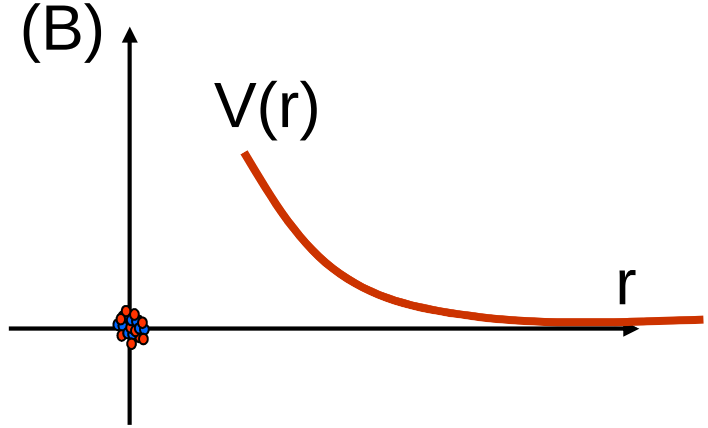
Analyzing alpha decay

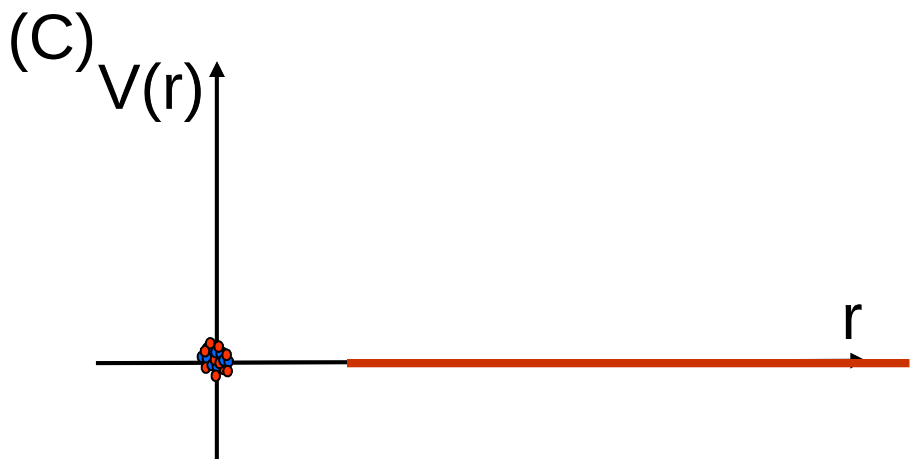
As we bring α closer, what happens to potential energy?



V=0 at a great distance



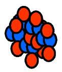




(D) Something else

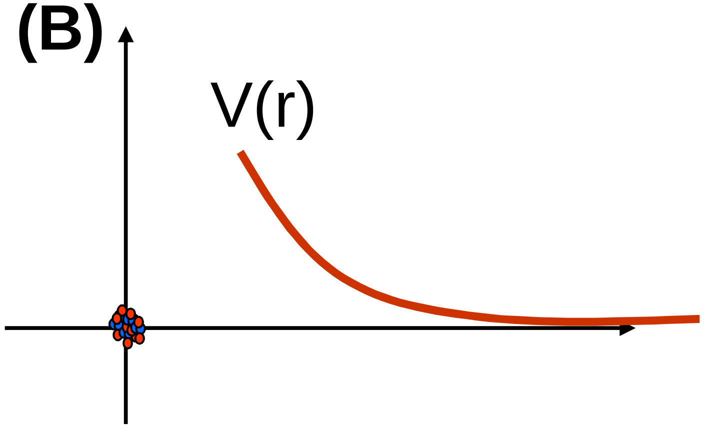
Analyzing alpha decay

As we bring α closer, what happens to potential energy?



V=0 at a great distance

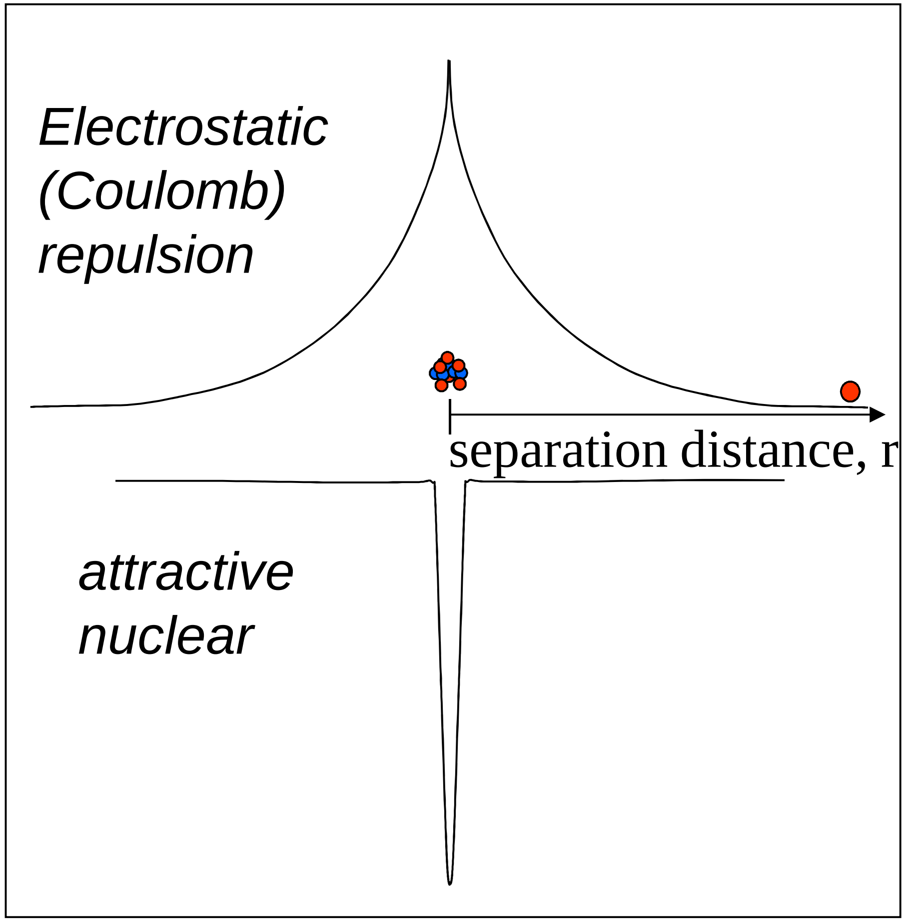
(B)



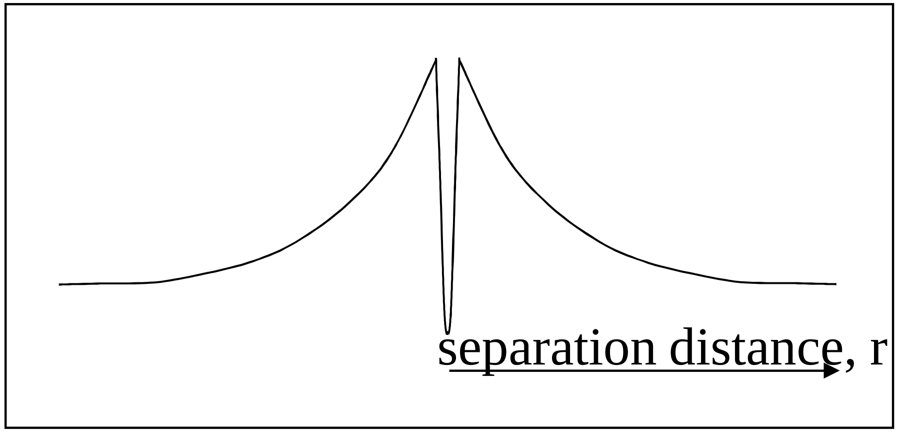
$$V(r) = \frac{kq_1q_2}{r} = \frac{\overbrace{k(Z-2)(e)}^{\text{nucleus}}\overbrace{(2e)}^{\alpha}}{r}$$

Takes energy to push α towards the nucleus, so potential energy must increase.

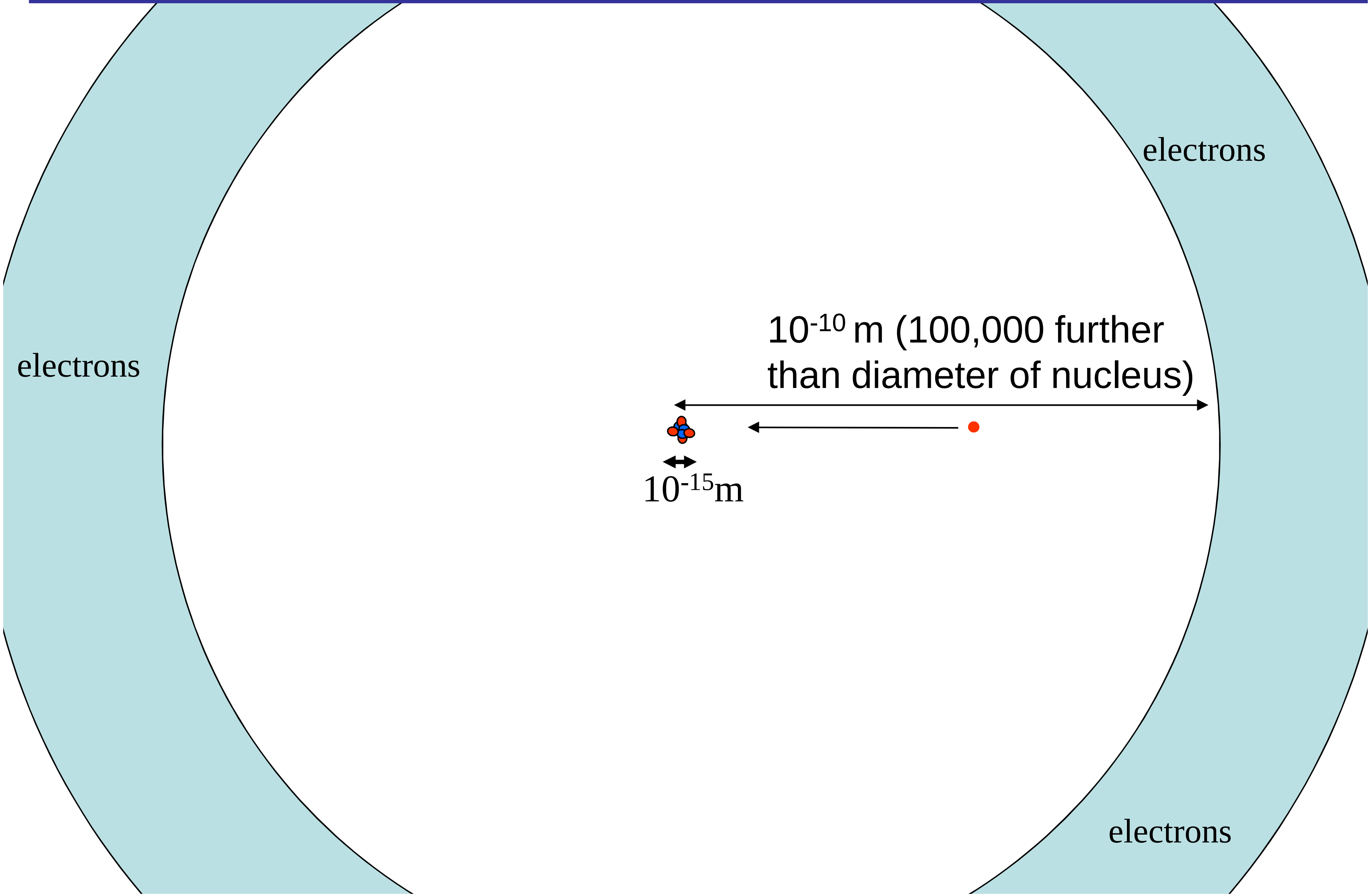
Potential energy curve for alpha decay



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.

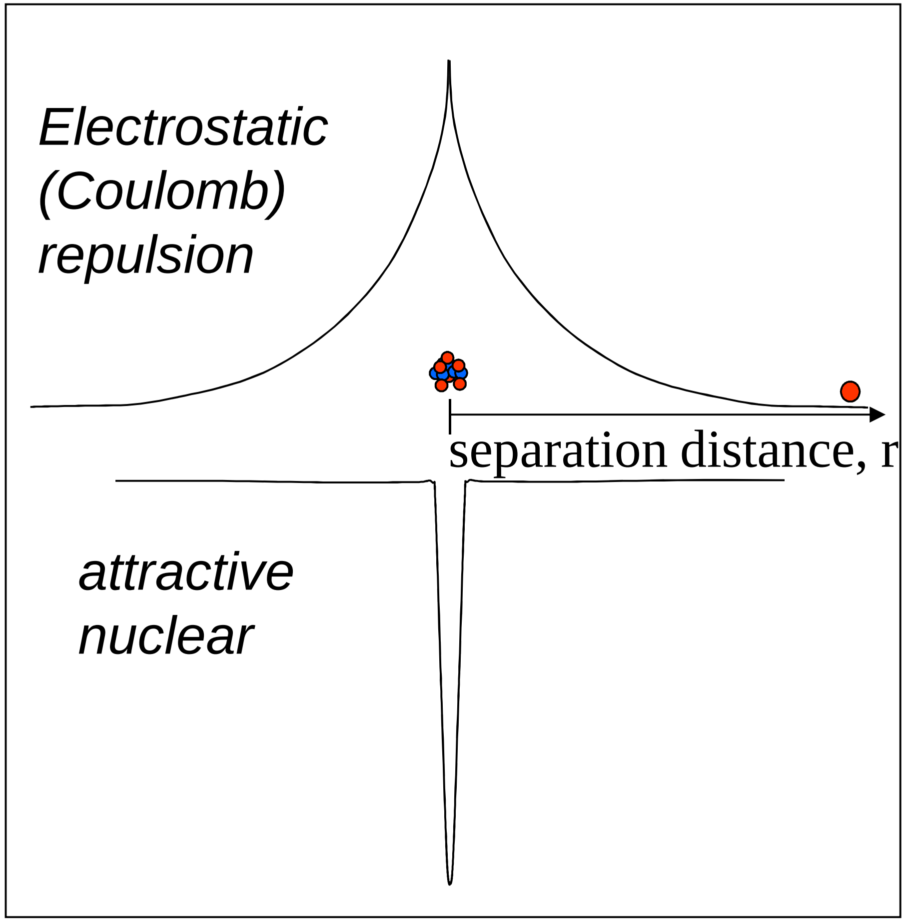
$$F = \frac{k\,(\text{charge of \#1})(\text{charge of \#2})}{r^2}$$

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

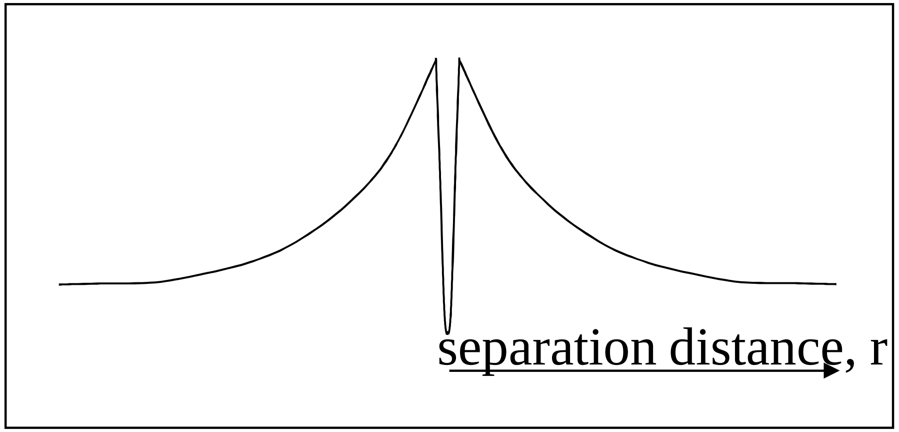
Nuclear forces - forces between protons on distance scale 10-100,000 times smaller.
10,000 times closer means forces **100,000,000 times bigger** because of $1/r^2$. Lots more potential energy stored !!!

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

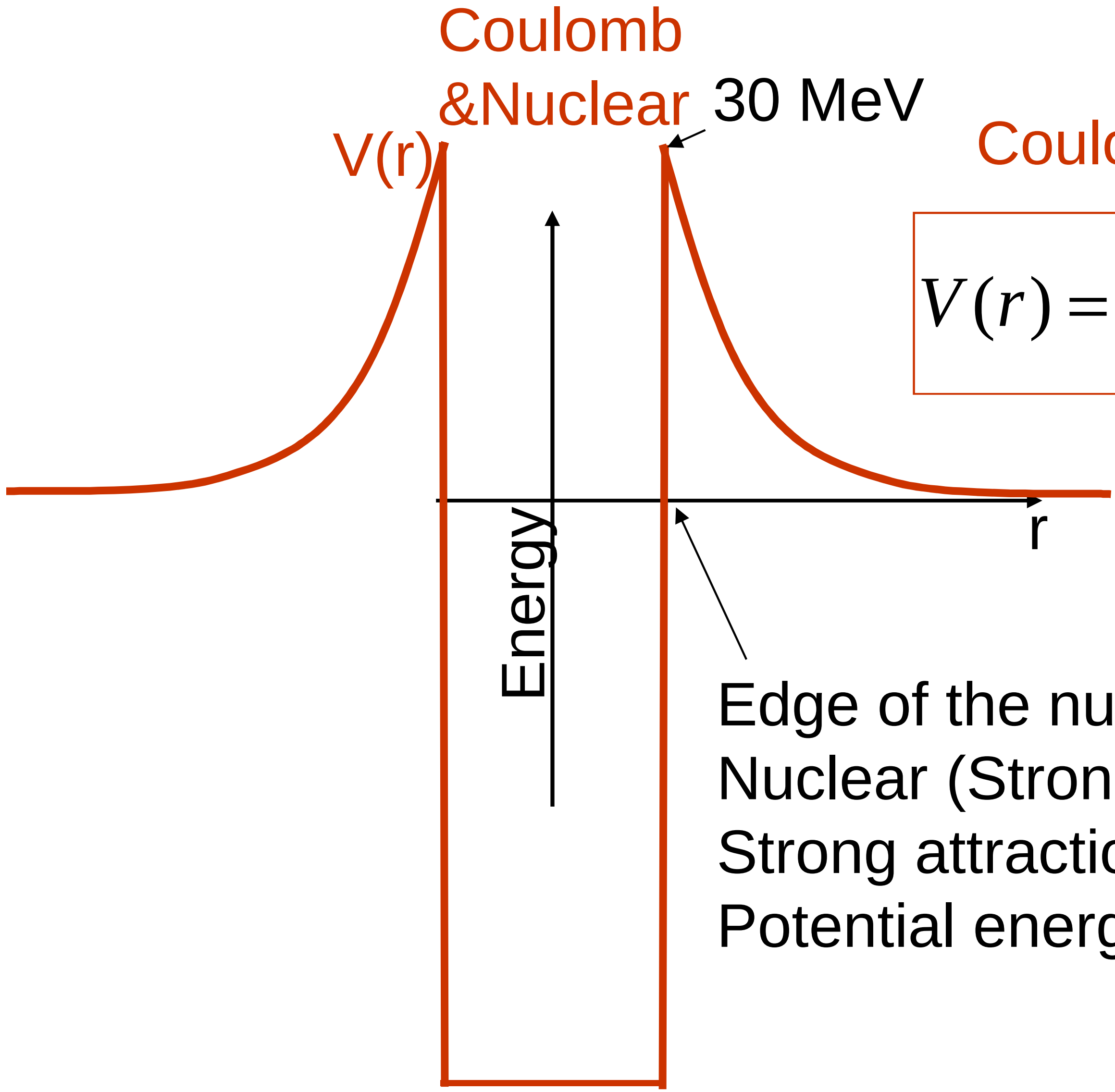
Potential energy curve for alpha decay



Superposition - real nucleus



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

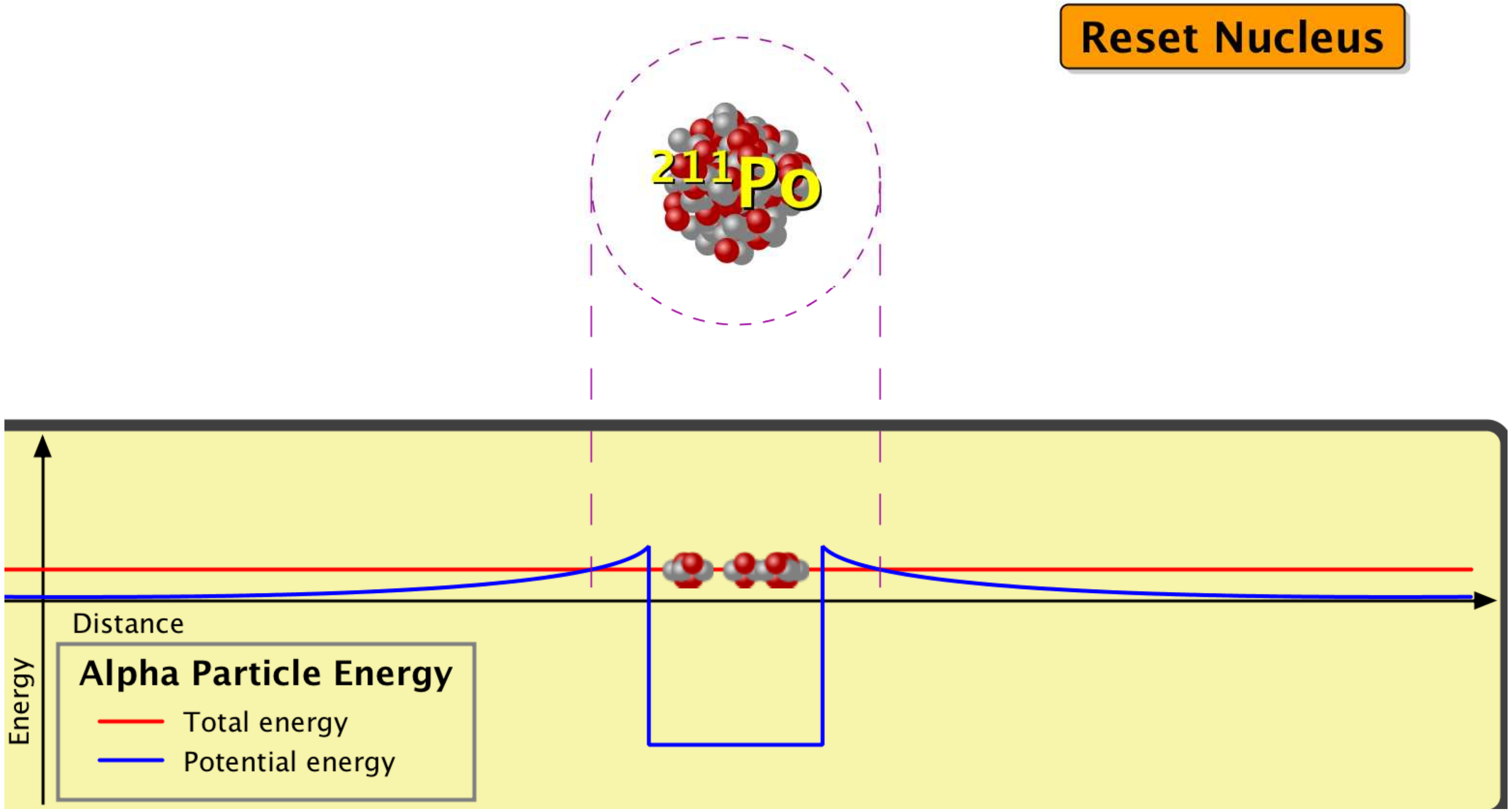


Coulomb force dominates

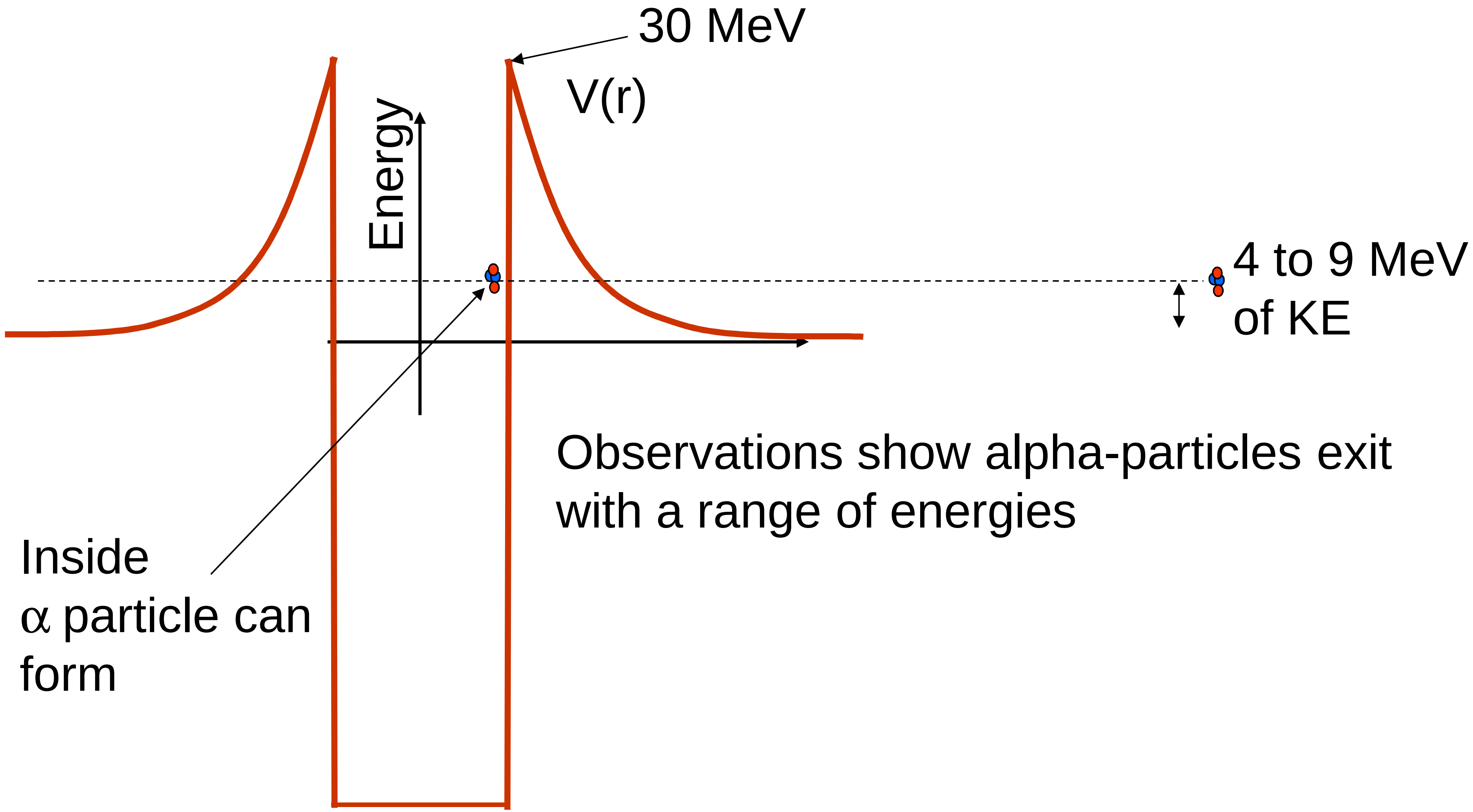
$$V(r) = \frac{kq_1q_2}{r} = \frac{k(Z-2)(e)(2e)}{r}$$

Edge of the nucleus (~8x10^{-15} m),
Nuclear (Strong) force starts acting
Strong attraction between nucleons
Potential energy drops dramatically

Alpha Decay Sim

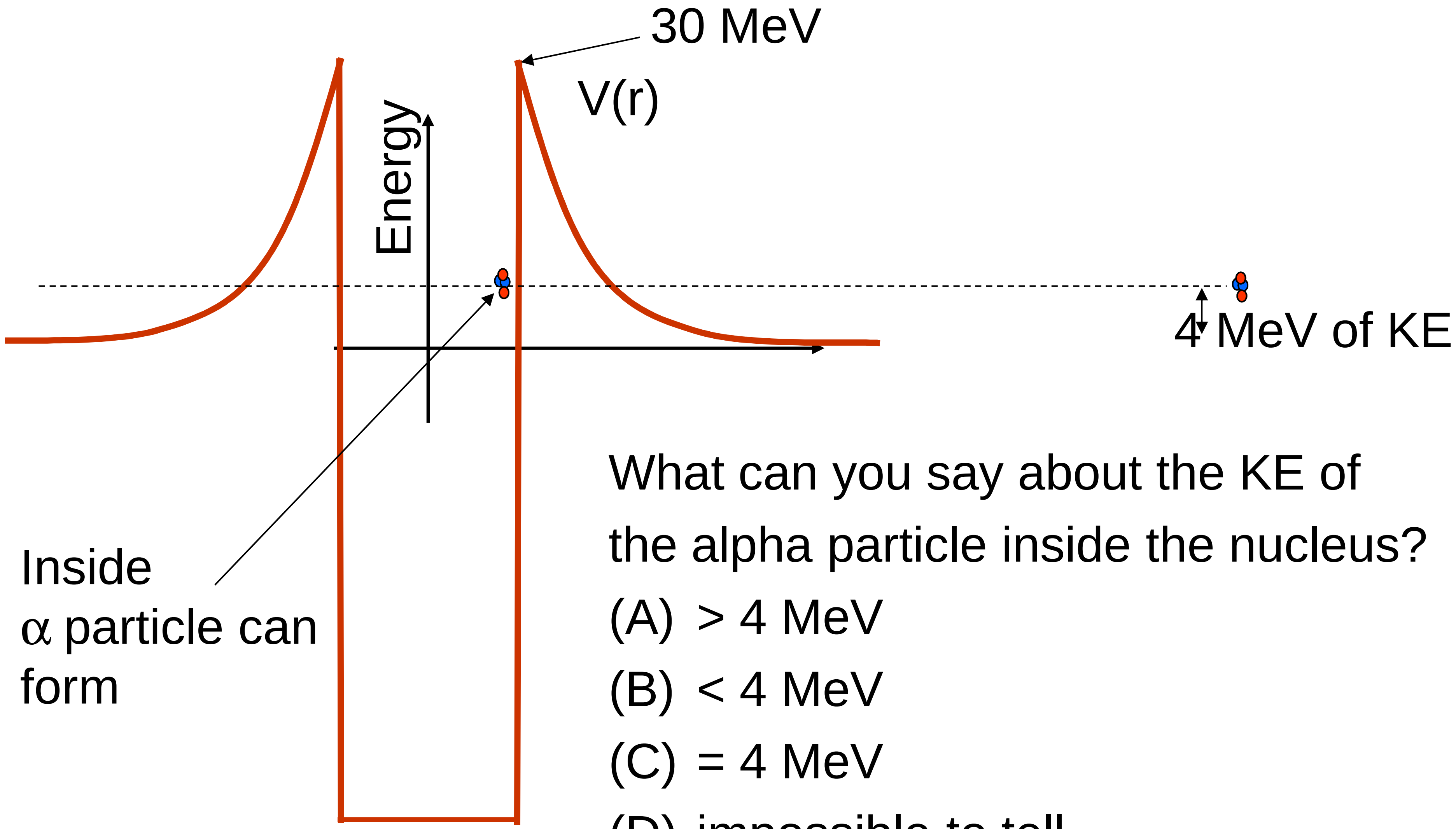


Quantum Tunneling: α-decay



Observations show alpha-particles exit with a range of energies

Quantum Tunneling: α-decay



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

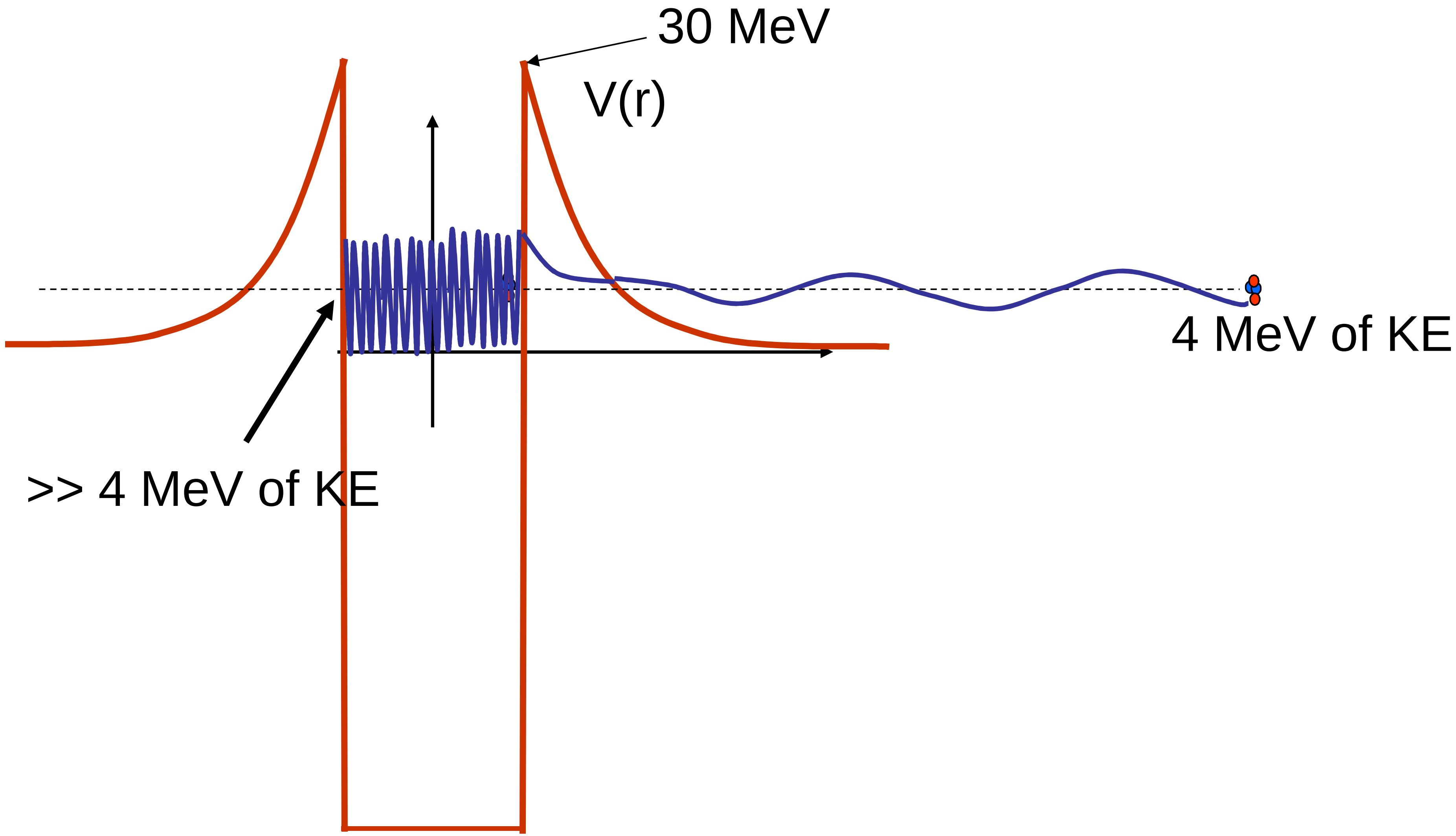
(A) > 4 MeV

(B) < 4 MeV

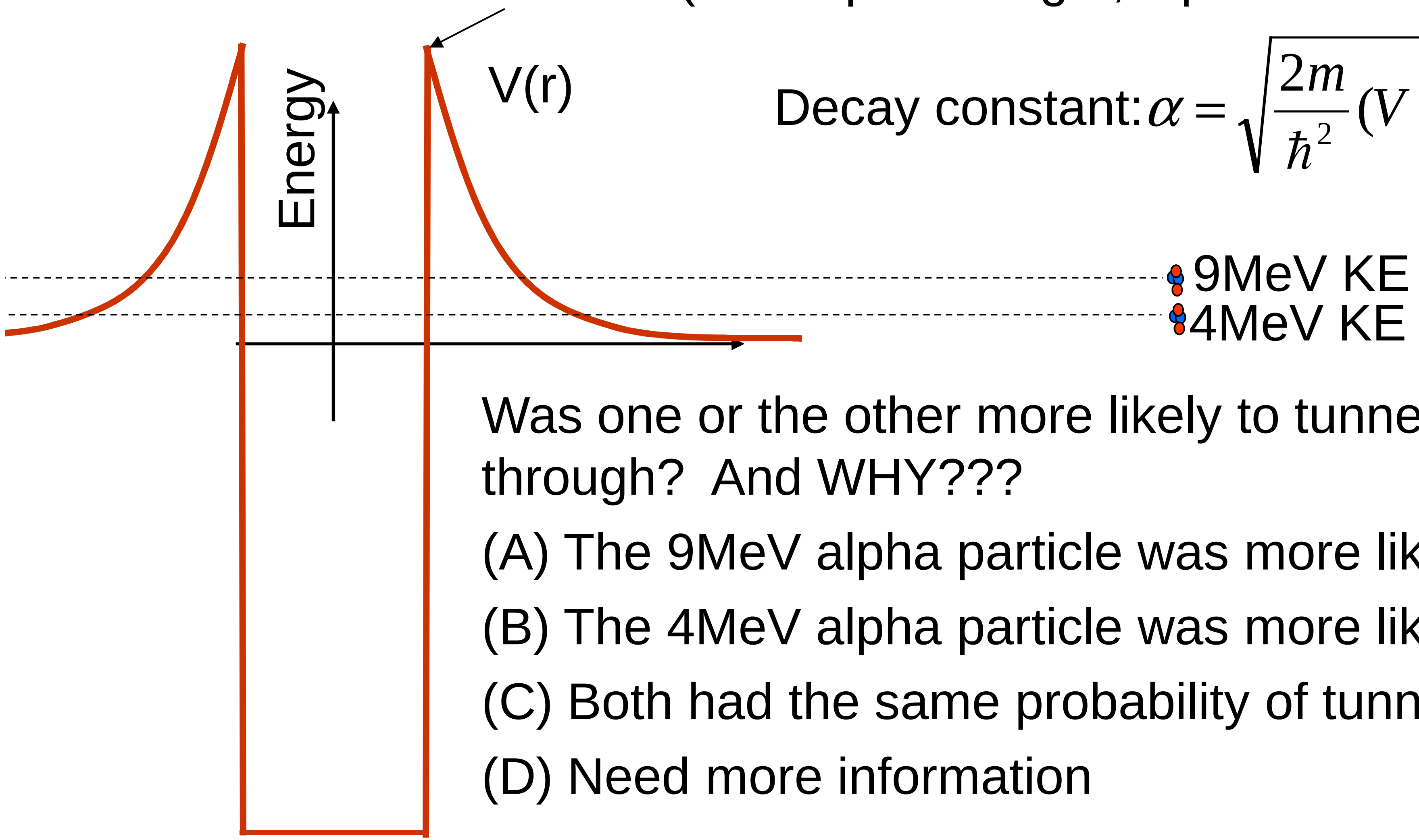
(C) = 4 MeV

(D) impossible to tell

Quantum Tunneling: α-decay



Observe α-particles from **<u>different isotopes</u> (same protons, different neutrons)**, exit with different amounts of energy.



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

Was one or the other more likely to tunnel through? And WHY???

(A) The 9MeV alpha particle was more likely

(B) The 4MeV alpha particle was more likely

(C) Both had the same probability of tunneling

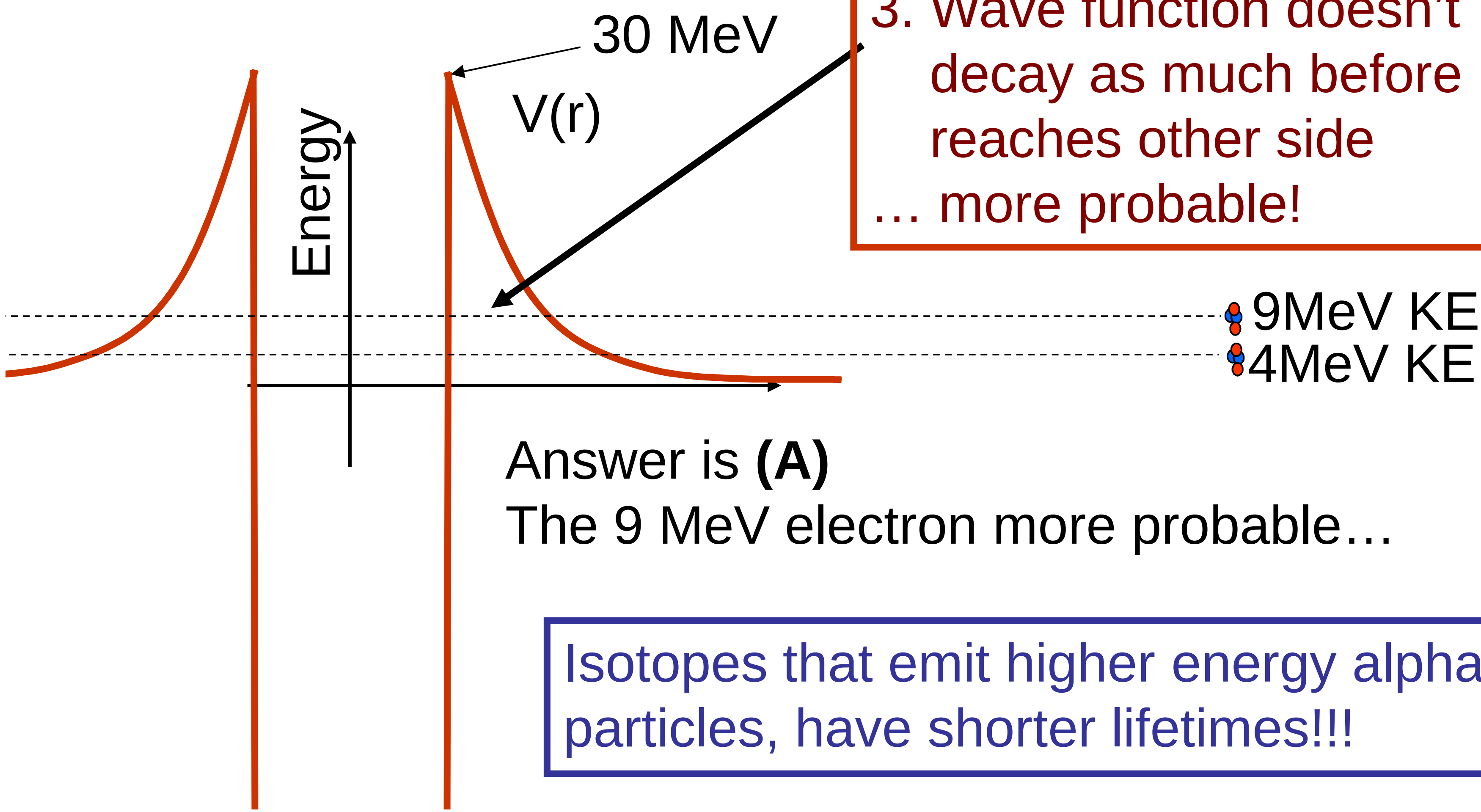
(D) Need more information

Observe a particles from **<u>different isotopes</u> (same protons, different neutrons),** exit with different amounts of energy.

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

1. Less distance to tunnel,
2. Decay constant always smaller
3. Wave function doesn't decay as much before reaches other side

… more probable!



Answer is **(A)**

The 9 MeV electron more probable…

Isotopes that emit higher energy alpha particles, have shorter lifetimes!!!