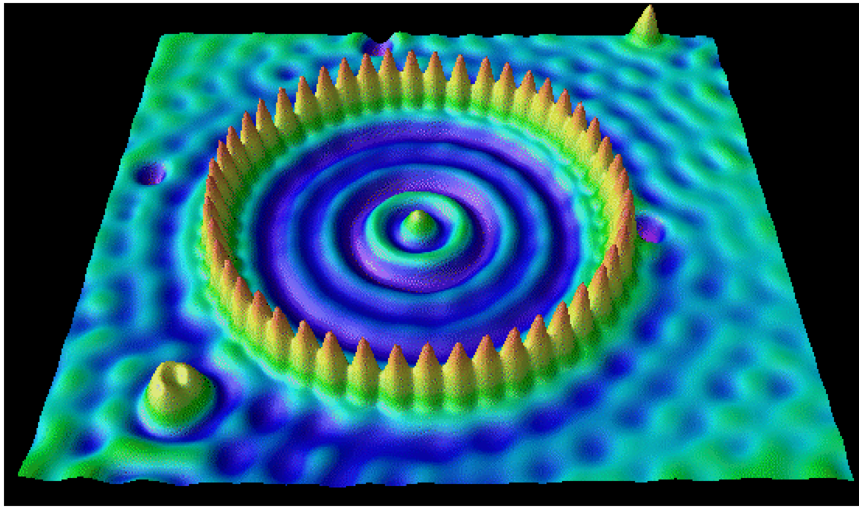
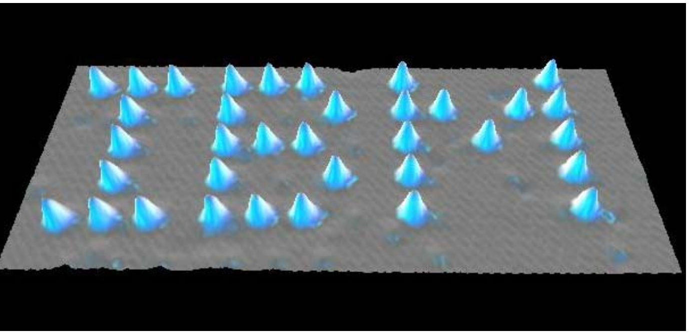
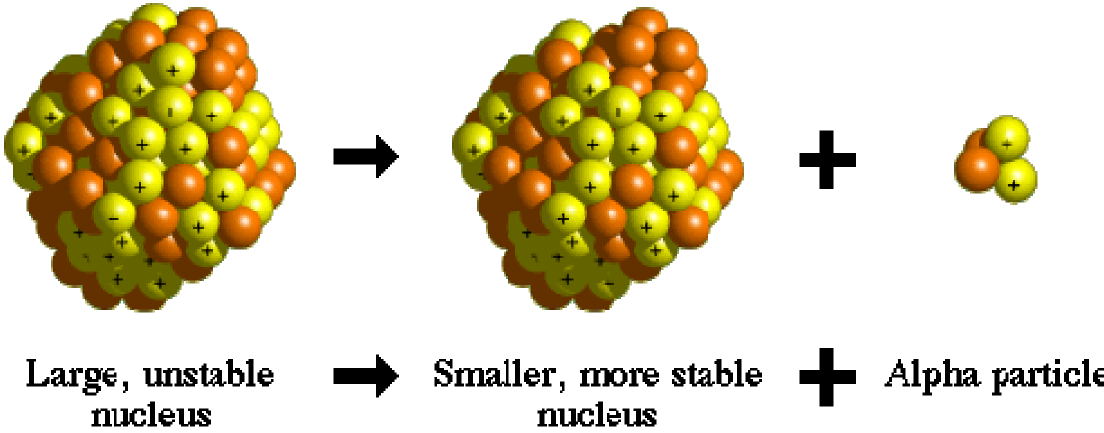
Quantum tunneling: α-decay

Announcements:

- Exam 2 is done. Please check to make sure I added your scores correctly.
- Exam 2 and HW1-10 scores are on CULearn.
- Homework set 12 is available on the web site.



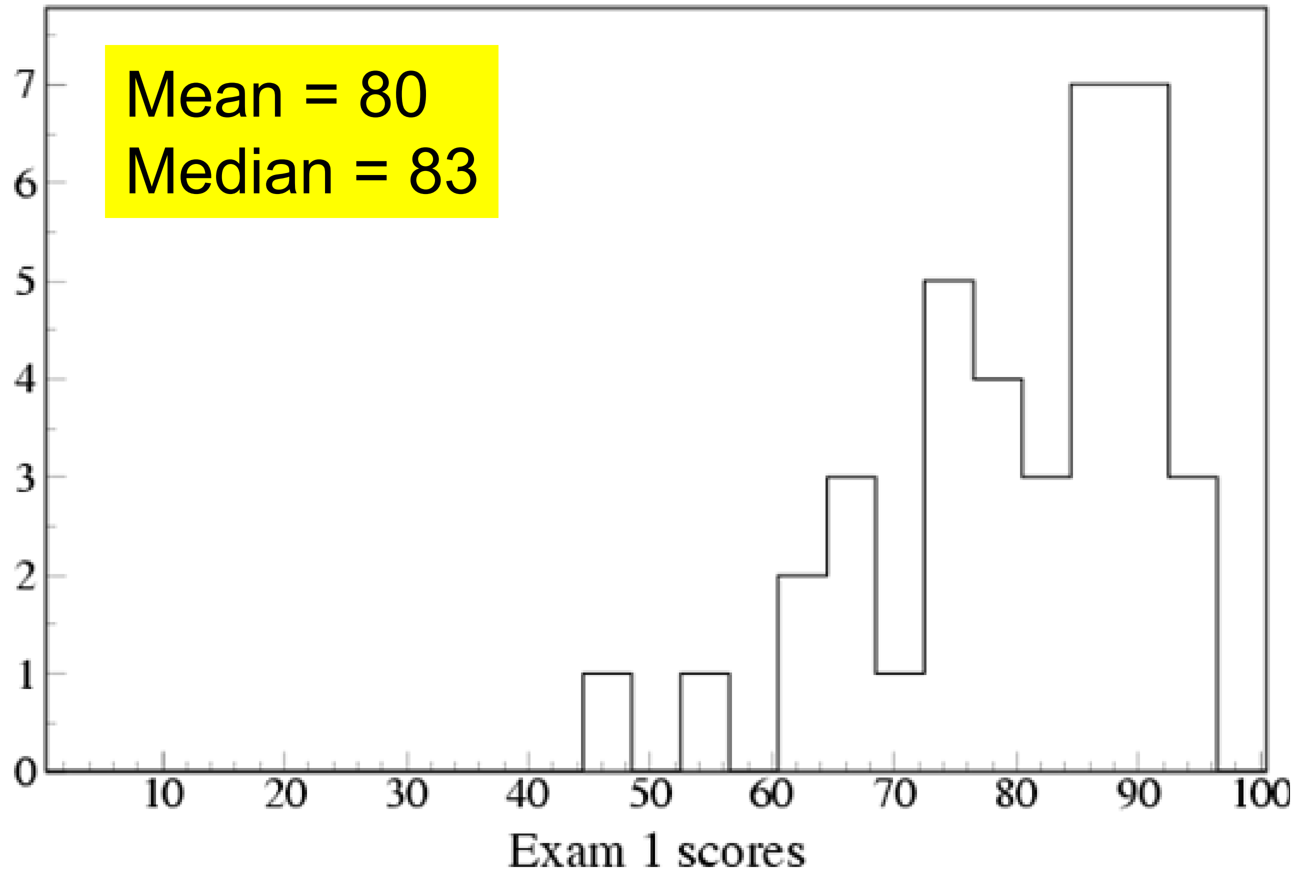




Exam 2 results

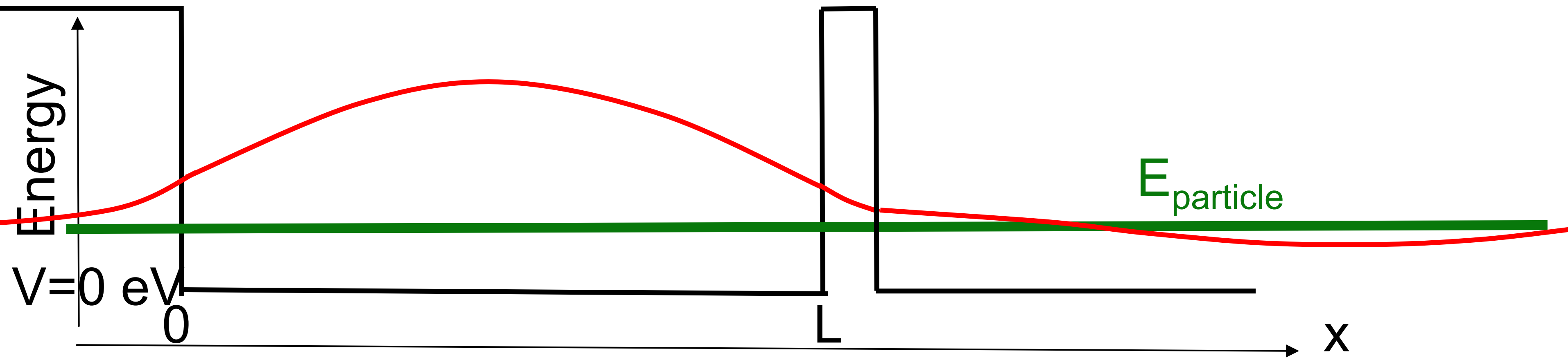
The average was 5 points higher than the previous exam. For the people taking both exams the average was 2.5 points higher.

One way to consider the extra credit is as an addition to your exam score. Based on the way the percentages work out, you can take your HW11 score, divide by 4 and add to your exam 2 score.



Quantum tunneling

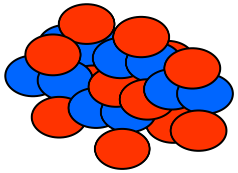
The thinner or shorter the barrier, the easier it is to tunnel …



Examples:

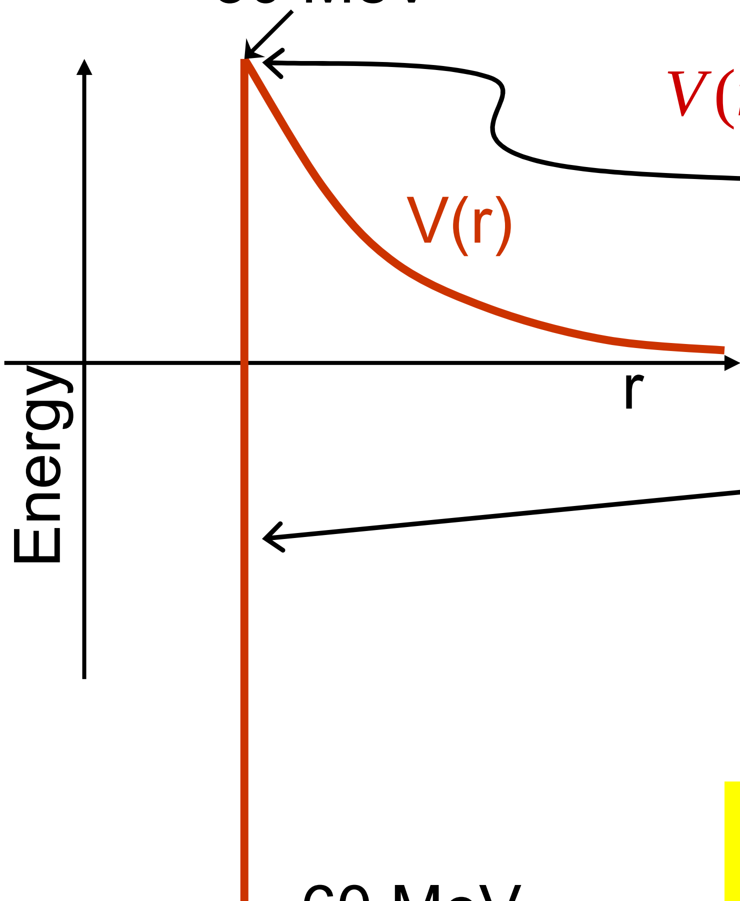
- Electron in wire going through air gap (Tutorial)
- Alpha decay: Explained by Gamow and seen in smoke detectors, radon, space probe power, and assassinations
- Scanning tunneling microscope
- Getting shocked when touching door knob

Potential energy curve for alpha decay



Radon-222
86 protons,
136 neutrons

Bring alpha-particle closer



Outside nucleus, Coulomb force dominates

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

What is the max height of *V(r)*?

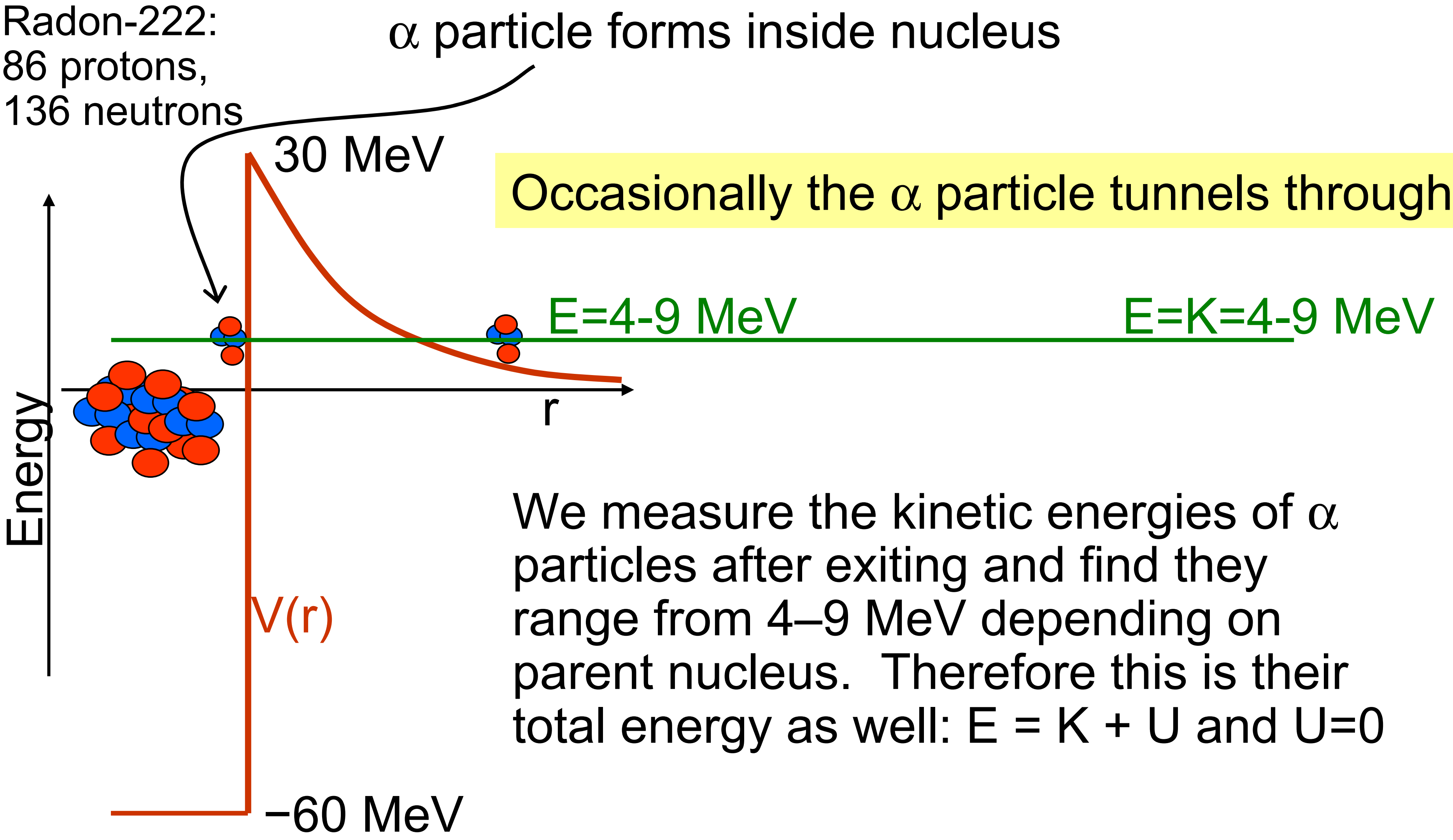
Nucleus has radius of 8 fm = 8×10^{-15} m so this is where the strong force takes over.

$$V(8\,\text{fm}) = \frac{(1.44\,\text{MeV}\cdot\text{fm})(84)(2)}{8\,\text{fm}} = 30\,\text{MeV}$$

Strong force dominates at *r*<8 fm and behaves like a deep potential well.

Potential energy curve for alpha decay

Radon-222:
86 protons,
136 neutrons

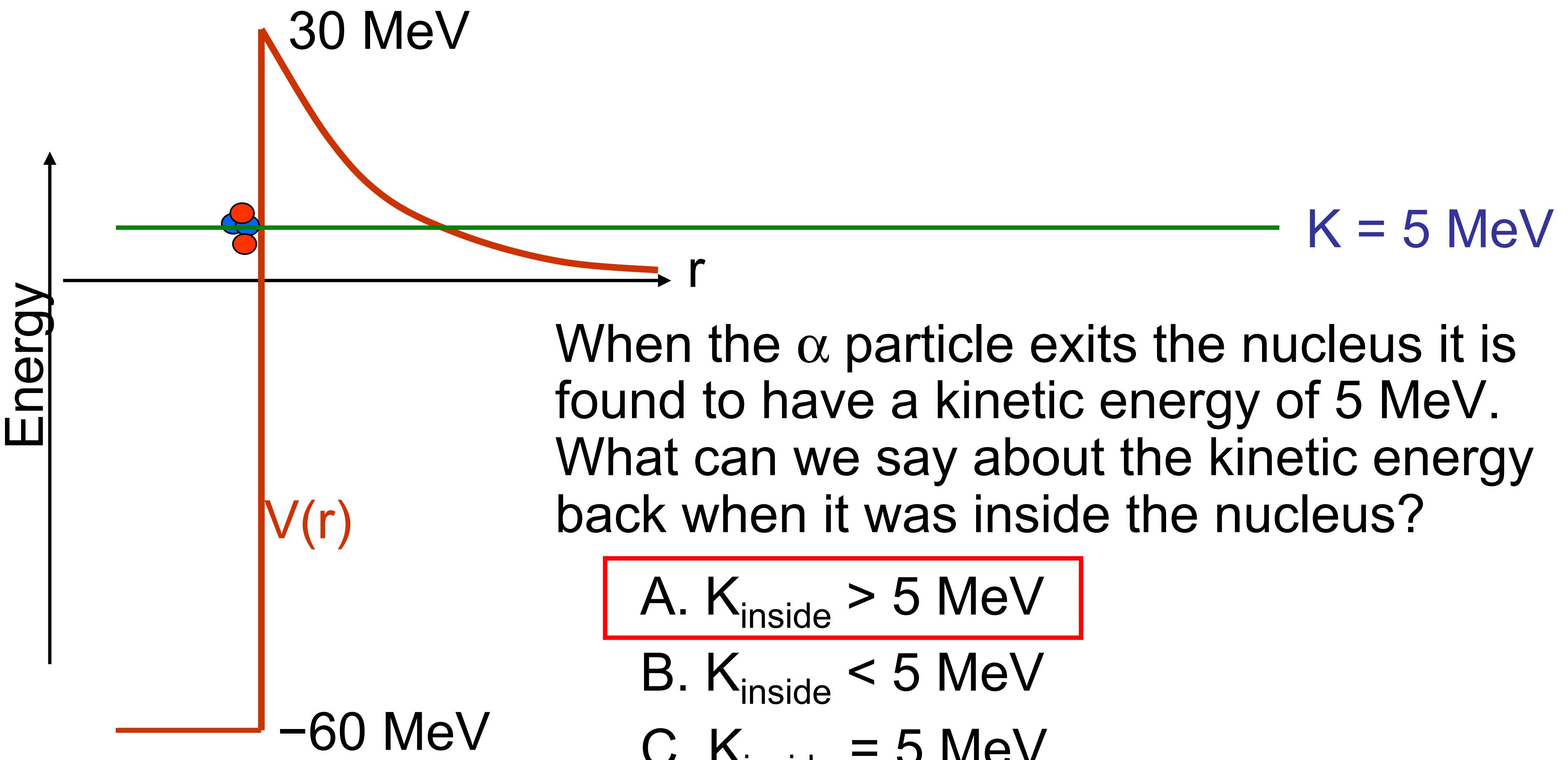


Occasionally the α particle tunnels through

We measure the kinetic energies of α particles after exiting and find they range from 4–9 MeV depending on parent nucleus. Therefore this is their total energy as well: $E = K + U$ and $U=0$

Clicker question 1

Set frequency to DA

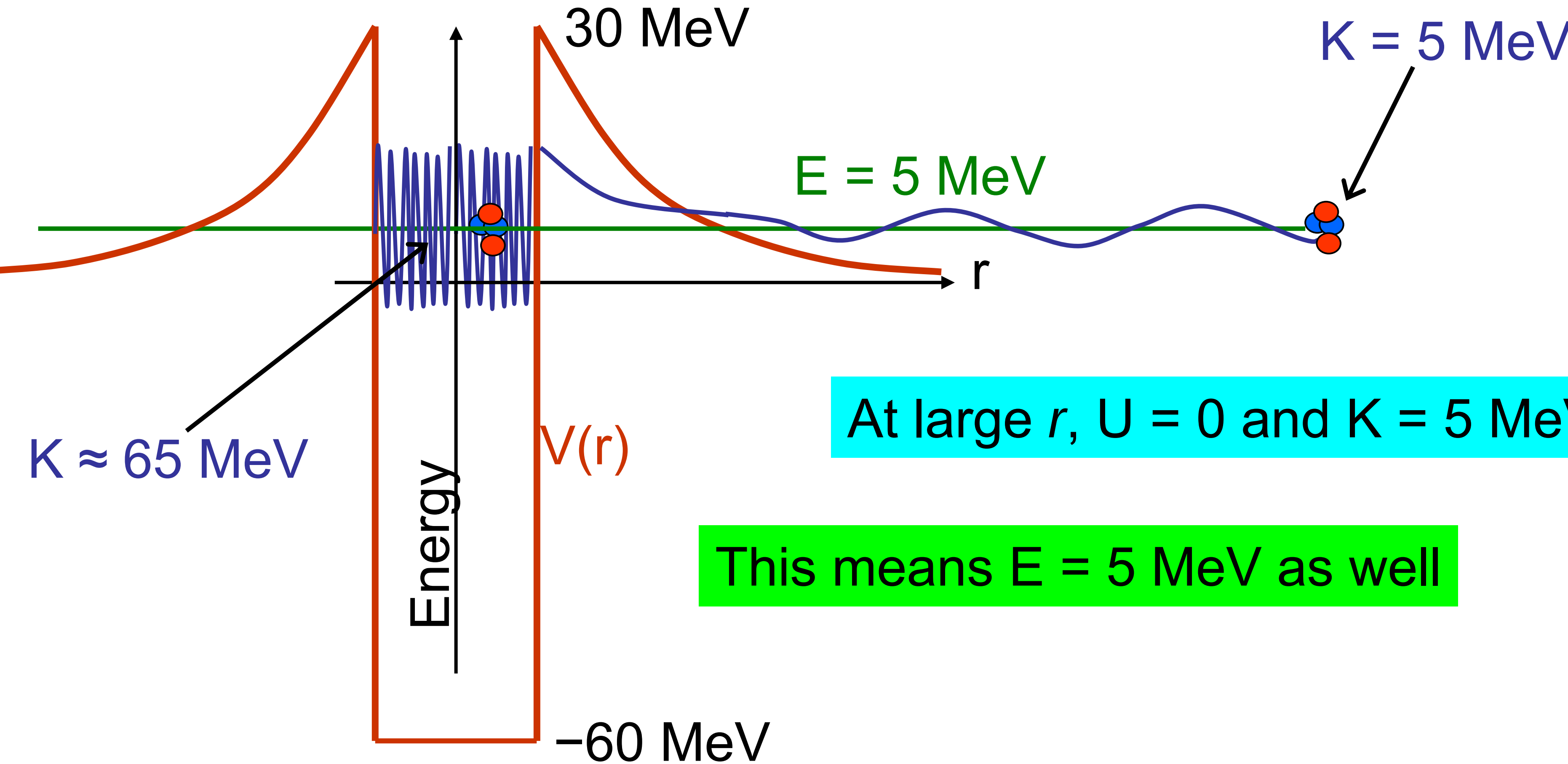


When the α particle exits the nucleus it is found to have a kinetic energy of 5 MeV. What can we say about the kinetic energy back when it was inside the nucleus?

A. $K_{inside} > 5$ MeV
B. $K_{inside} < 5$ MeV
C. $K_{inside} = 5$ MeV
D. Impossible to know

Energy ($E = K + U$) is conserved so $E = 5$ MeV.
Inside it has $U = -60$ MeV so $K = E - U = 65$ MeV.

Conservation of energy for the α particle



At large *r*, U = 0 and K = 5 MeV

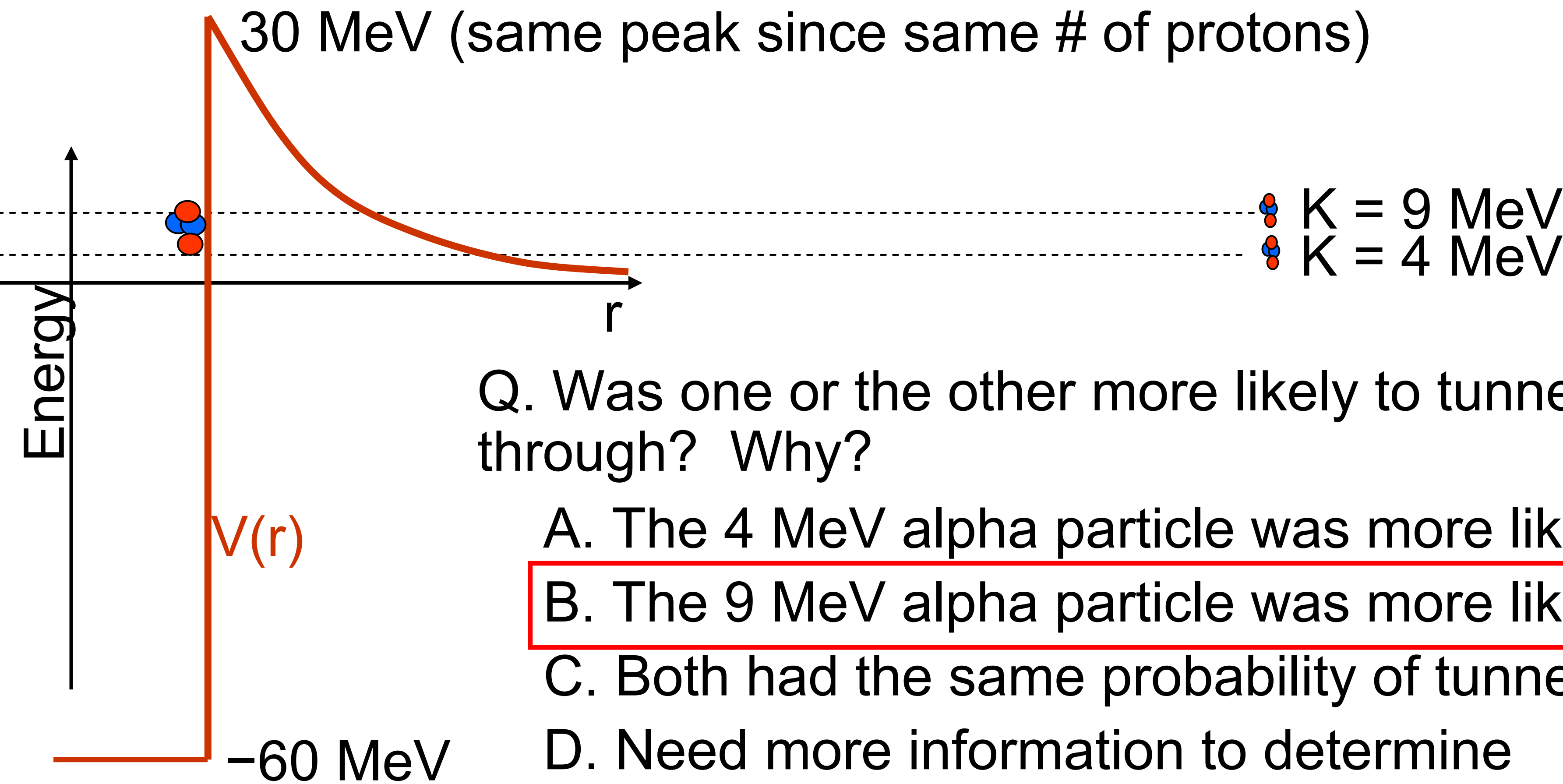
This means E = 5 MeV as well

Inside nucleus, U = −60 MeV and
E = 5 MeV so K = E – U = 65 MeV

Clicker question 2

Set frequency to DA

Experimentally, we find that different isotopes (same # of protons, different # of neutrons) emit α particles with different energies.



Q. Was one or the other more likely to tunnel through? Why?

A. The 4 MeV alpha particle was more likely

B. The 9 MeV alpha particle was more likely

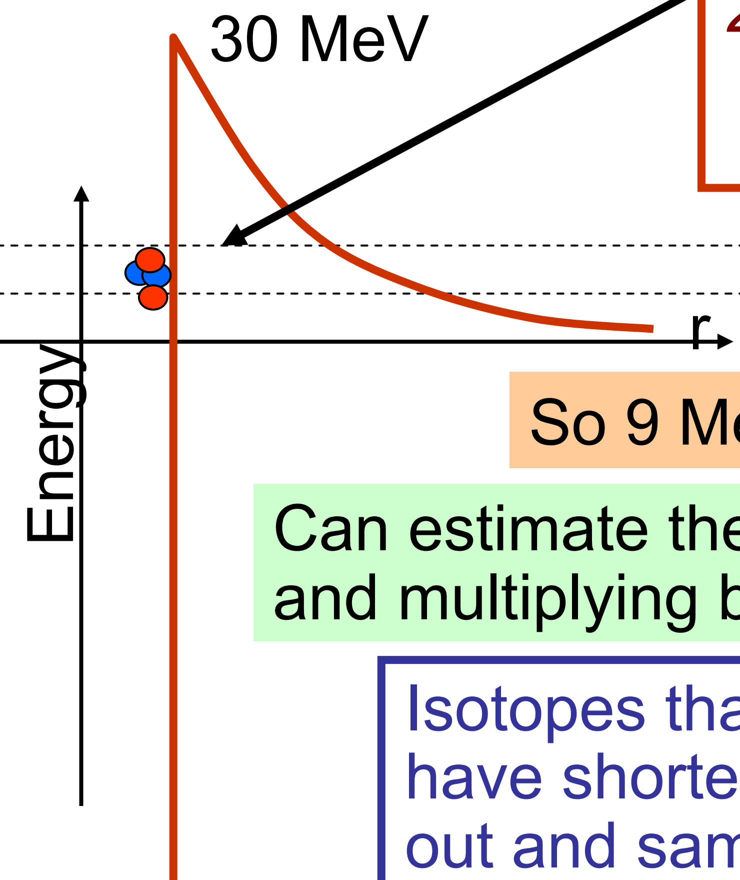
C. Both had the same probability of tunneling

D. Need more information to determine

α decay probability

Probability of tunneling is $P \approx e^{-2\alpha L}$ where $\alpha = \frac{\sqrt{2m(V-E)}}{\hbar}$

1. Less distance to tunnel (smaller *L*)
2. Decay constant α is smaller so wave function doesn't decay as much before reaching other side



So 9 MeV α has a higher tunneling probability

Can estimate the α decay **rate** by taking the probability and multiplying by how often the α particle hits the barrier

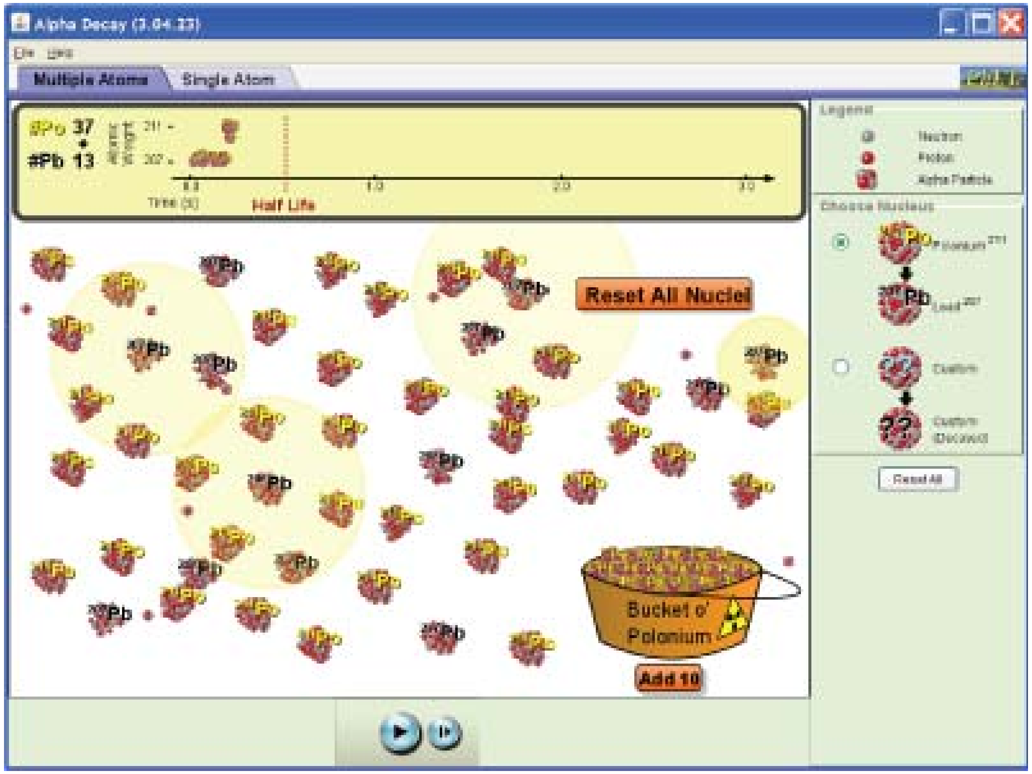
Isotopes that emit higher energy α particles should have shorter lifetimes (higher probability to tunnel out and same frequency of hitting nuclear surface)

Experimentally confirmed! See text for details.

Alpha decay simulation

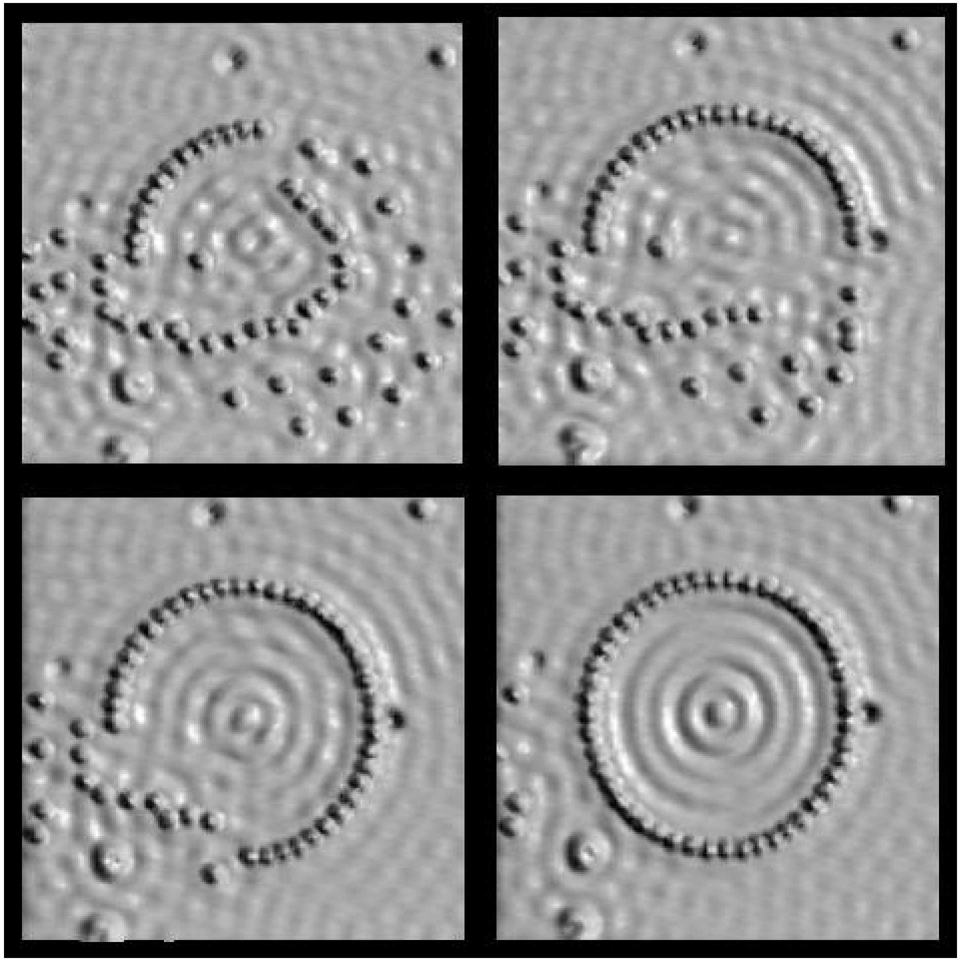
http://phet.colorado.edu/simulations/sims.php?sim=Alpha_Decay

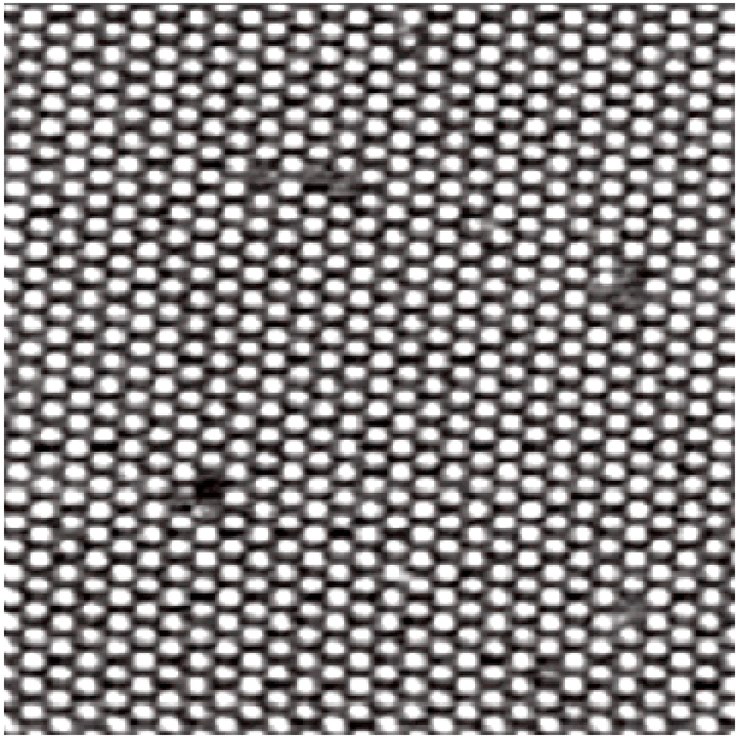
You can check it out if you like. The custom nucleus is probably the most useful feature.



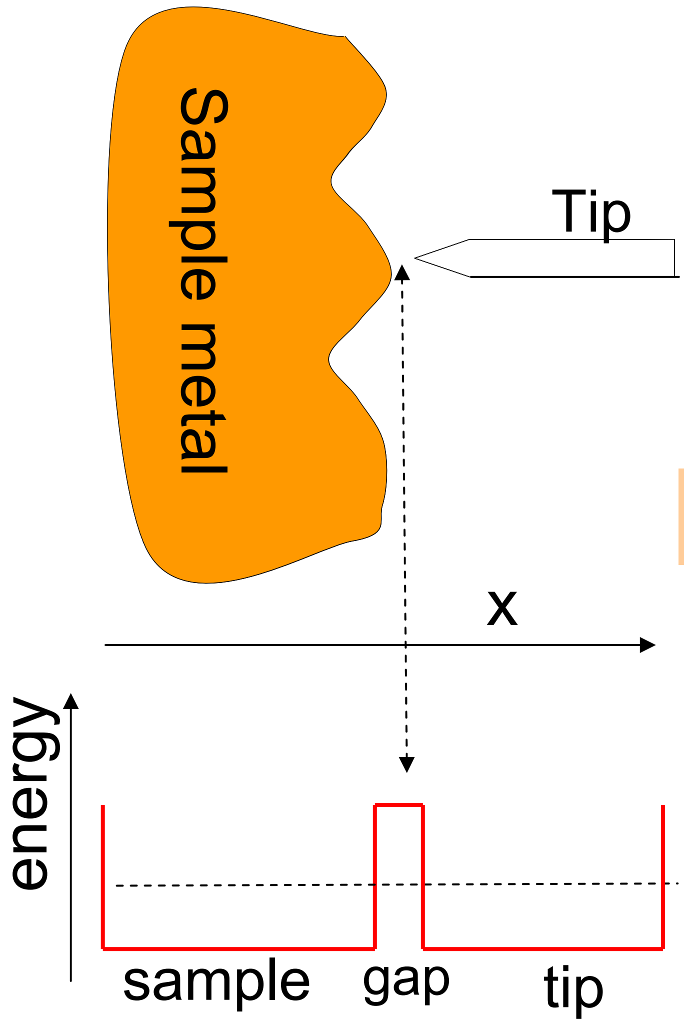
Scanning tunneling microscope

Use tunneling to measure small changes in distance.
Nobel prize winning idea: invention of “scanning tunneling microscope (STM)”. Measure atoms on surfaces.





An STM start

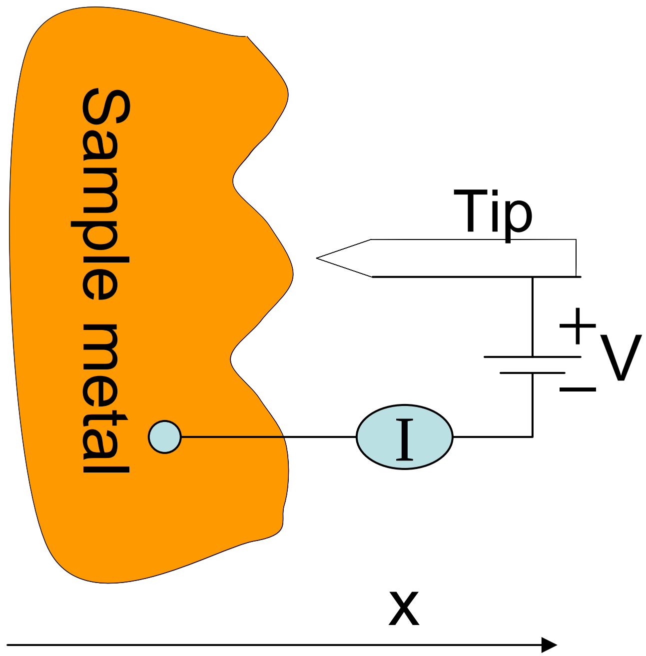


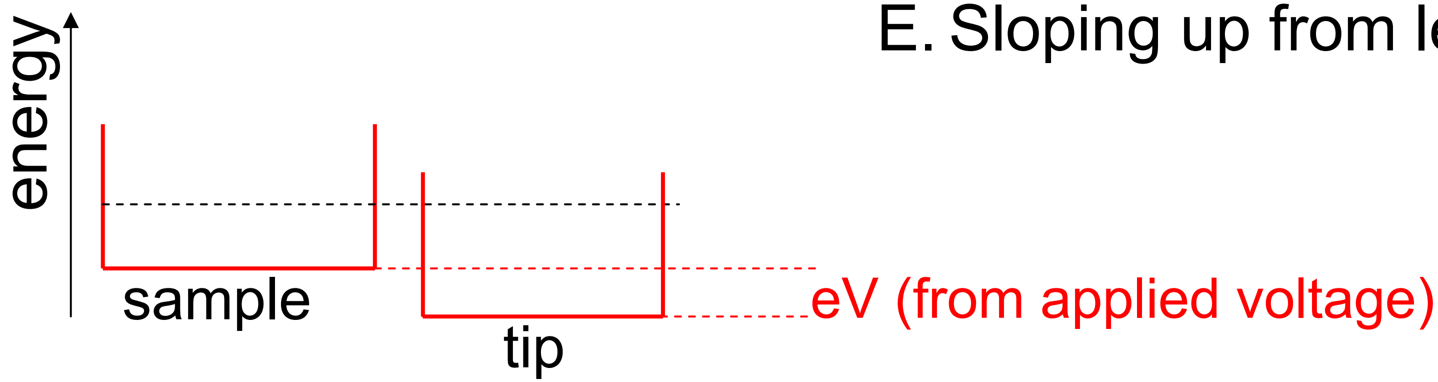
What does the potential look like to an electron for this setup?

Assume the work function of both metals is the same.

Will there be any tunneling in this case?

Individual electrons will tunnel in either direction but it will be an equal number so there will be no current flow.



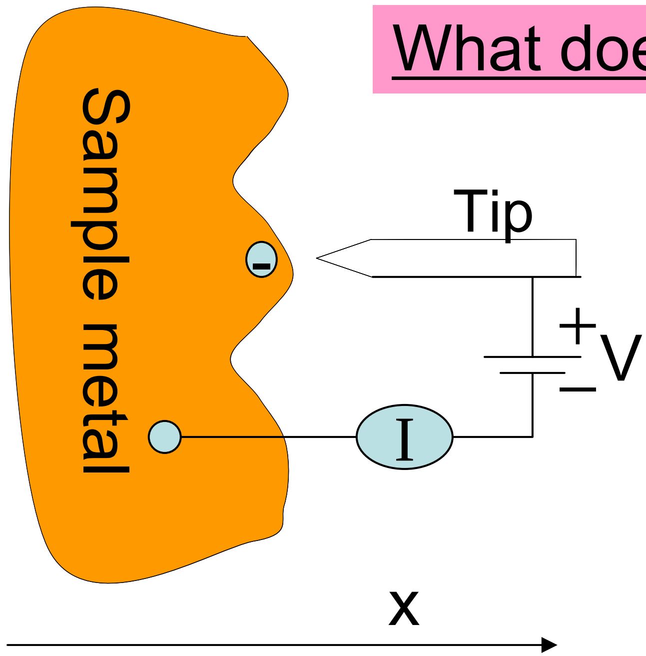


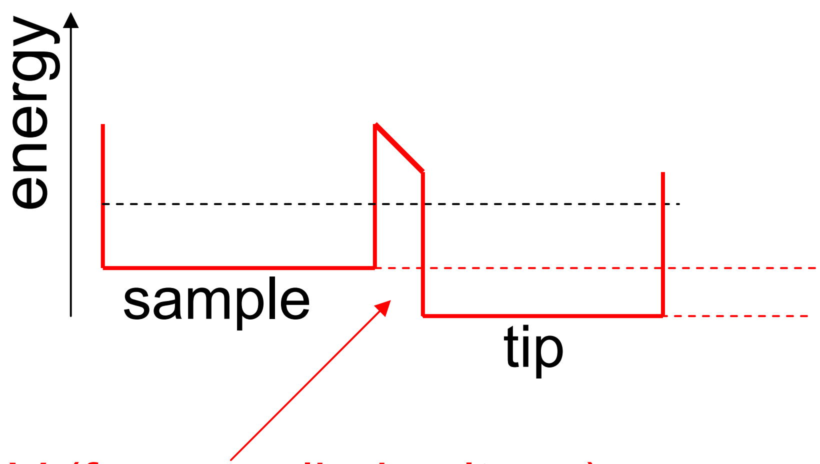
Again, assuming the work function of both metals is the same, what does the potential in the **tip** look like compared to the sample?

A. Same
B. Same shape but lower level
C. Same shape but higher level
D. Sloping down from left to right
E. Sloping up from left to right

STM potential energy curve

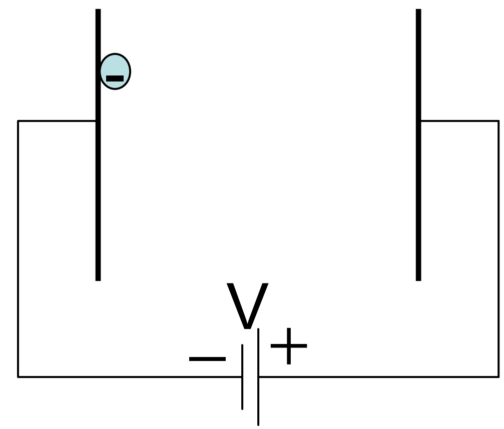
What does the potential in the air gap look like?





eV (from applied voltage)

Consider a parallel plate capacitor



As electron accelerates across, it linearly loses potential energy and gains kinetic energy.

Same holds true here.