2026 Boston QuarkNet Summer Workshop
Quantum Tunneling

DATE: August 13-14, 2026

Activity 1 Radioactive Decay Series

1. Get a chart for one of the four natural radioactive decay series (Uranium, Actinium, Thorium, Neptunium).

2. Use the sequence of α and β decays to fill in the isotopes on the chart from the beginning isotope at the top right to the stable end point isotope at the bottom left of your series.

3. Compare your isotope sequence with those of others who had the same series and reconcile any differences.

Activity 2 Radioactive Half-life ($t_{1/2}$)

1. Values for the average number of a decays in 1.00 s for 0.01 g of the starting isotope of each decay series are given below.

   U-238: 124.4 Bq, Pu-239: 2.29×10^7 Bq,
   Th-232: 40.7 Bq, Np-237: 2.60×10^5 Bq
   Bq = becquerel = 1 decay/s = s^{-1}

2. Use the intensity value (I) for the starting isotope in your series to calculate the half-life ($t_{1/2}$) of that isotope.

3. Work collaboratively to devise a calculation procedure, OR work individually then compare your procedures and results.

Activity 3 α-particle Energy Measurement

1. Measure the maximum range (cm) of Po-210 α-particles in a cloud chamber.

2. Compare your measured range to the range expected for 5.3 MeV α-particles from Po-210 decay.
   An empirical approximation relating α-particle range (*R in cm*) in air at STP and α-particle kinetic energy (*KE* in MeV) is
   $$R_{air} \cong (0.005KE + 0.285)KE^{3/2} .$$
   L'Annunziata, *Radioactivity: Introduction and History*, Elsevier, Amsterdam, 2007, p, 78.

Activity 4 α-Particle Energy Calculation

Masses of nuclides in Po-210 decay:

Po-210	210 Da – 15.9531 MeV/c^2
Pb-206	206 Da – 23.7855 MeV/c^2
He-4	4 Da + 2.4249 MeV/c^2

[National Nuclear Data Center, https://www.nndc.bnl.gov/nudat3/ accessed April 17, 2026]

NOTE: 1 Da = Dalton = $\frac{1}{12}$(mass of C12) = 931.494 MeV/c^2

1. Calculate the total KE available to (Pb-206 + α-particle) in the decay.

2. Calculate the expected α-particle KE.

   Compare to observed α-particle KE for this decay.

Activity 5 α-Particle Binding Energy

1. Calculate the binding energy of an α-particle, *i. e.* the energy needed to separate an α-particle into its constituent protons and neutrons.
   Proton mass = 938.272 MeV/c^2 Neutron mass = 939.565 MeV/c^2
   α-particle mass = 3,727.379 MeV/c^2

2. Calculate the binding energy per nucleon of an α-particle.

3. Why don't heavy nuclei eject protons, rather than α-particles?

Activity 6 α-Particle Decay Patterns (Discussion)

1. Get the *Radioactive Decay Series* sheets that include α and β energies and half-lives.

2. What pattern between an α-particle kinetic energy (KE_α) and its starting distance from the nucleus ($r_{\alpha min}$) do you expect?

3. What relationship do you notice between an emitted α-particle kinetic energy (KE_α) and decay half-life ($t_{1/2}$) of its parent nucleus?

4. How could you plot values on graphs to look for patterns?

<u>Activity 7</u> α-Decay Patterns (Plots)

1. Get the *Radioactive α-Decay Patterns* sheet for your decay series.
2. Collaborate with others who are working on the same decay series to calculate and fill in the values in the blank columns of the sheet.
   NOTE: Nuclear Radius = $r_0 A^{1/3}$, r_0 = 1.2 fm = proton radius.
3. What model of the nucleus does the Nuclear Radius formula reflect?
4. Plot the values of (KE_α, r_{amin}) and (KE_α, $\log_{10}(t_{1/2})$) for your series on the two graphs on the sheet.

<u>Activity 8</u> (KE_α, $r_{\alpha min}$) Plot Discussion

1. Draw a line representing the approximate value of the nuclear radii in your decay series on your KE_a vs. r_{amin} plot.
2. How are your r_{amin} values related to KE_a values?
   Explain the relationship.
3. How are your r_{amin} values related to your nuclear radii values?
4. Why is this relationship a problem?

Activity 9   Bohr Model of H Atom

Work with colleagues to do the calculations and algebraic derivations in the "Bohr Model of Hydrogen Atom Worksheet."

Activity 10   (KE_a, $\log_{10}(t_{1/2})$) Plot Discussion

1. What do you notice about your (KE_a, $\log_{10}(t_{1/2})$) plot?

2. How can the logarithmic relation be explained?

Activity 11   pp Solar Fusion

1. Calculate KE_1 (J and keV) required for each of two protons to achieve a separation of 2.4 fm during a collision to allow the strong force interaction to overcome electrical repulsion. Proton radius for strong force interactions is r_0 = 1.2 fm.
   $k_C = 9 \times 10^9$ N m^2 C^{-2} $q_p = 1.6 \times 10^{-19}$ C   1 MeV = 1.6×10^{-13} J

2. Calculate the speed v_1 of a proton with KE_1.

3. Calculate the most probable speed of a proton at the Sun's core temperature T = 16 x 10^6 K (Standard Solar Model). The most probable speed v_p for a Maxwell-Boltzmann (M-B) distribution of gas particle speeds is

   $v_{\mathrm{p}} = \sqrt{\frac{2k_{\mathrm{B}}T}{m}}$ k_B = 1.38 x 10^{-23} J K^{-1} m_p = 1.67 x 10^{-27} kg

4. Calculate the KE_p (J and keV) of a proton traveling at the most probable speed.

5. Calculate the approximate ratio of the fraction of protons in the Sun's core with KE_1 to the fraction of protons with KE_p . The M-B distribution for the fraction of particles at speed *v* is

   $f(v) = \left(\frac{m}{2\pi k_{\mathrm{B}}T}\right)^{3/2}(4\pi v^2)\exp\left(-\frac{mv^2/2}{k_{\mathrm{B}}T}\right).$

6. What problem does the result of #5 create? How can the problem be solved?