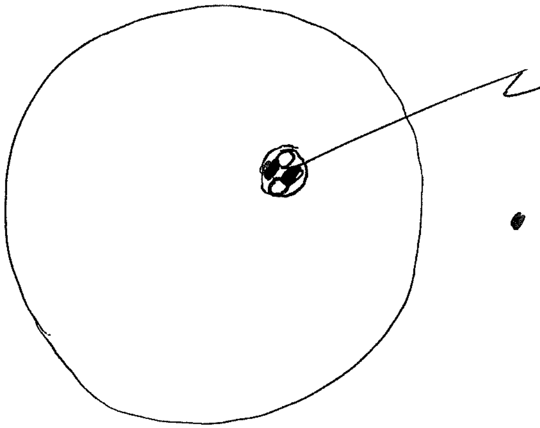
D. Back to tunneling and α-decay

- Gamov (1928) : α-decay comes from tunneling



^4_2He "grouped" occasionally

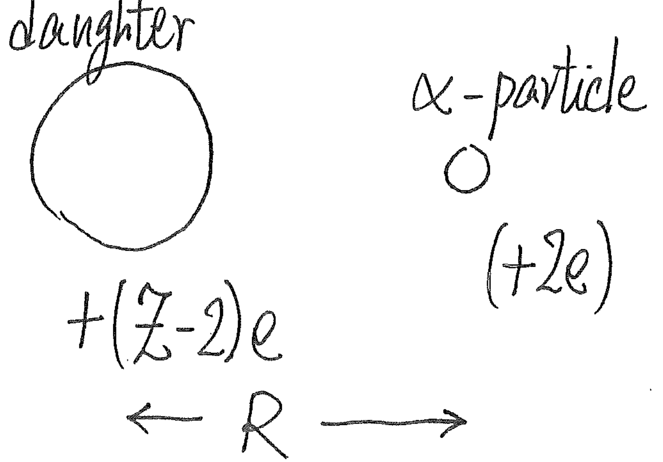
- travels toward surface

  ⇒ an attempt of tunneling

  [e.g. $^{232}_{92}U \rightarrow {}^{228}_{90}Th + \alpha$]

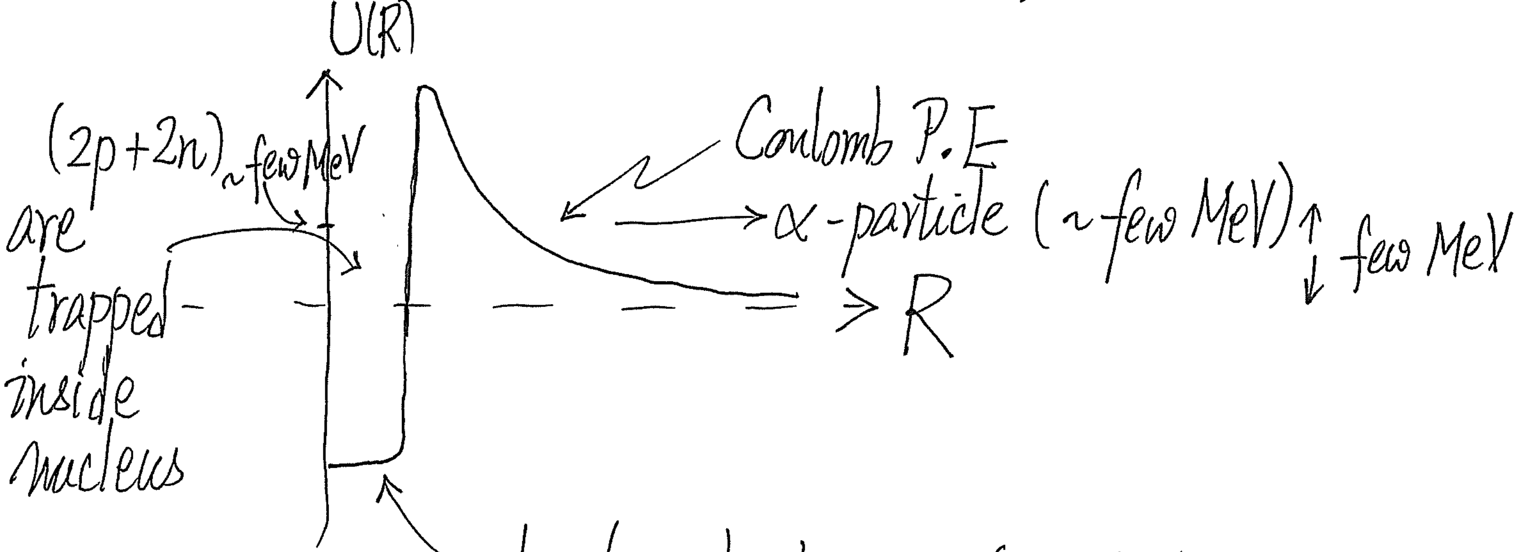
- But other nucleons ($^{228}_{90}Th$) exert attraction (nuclear force) and don't want α to leave ⇒ a barrier
- Once outside : α (+ve charge) and daughter nucleus (+ve charge) repel ⇒

don't want α to come back



Coulomb repulsion

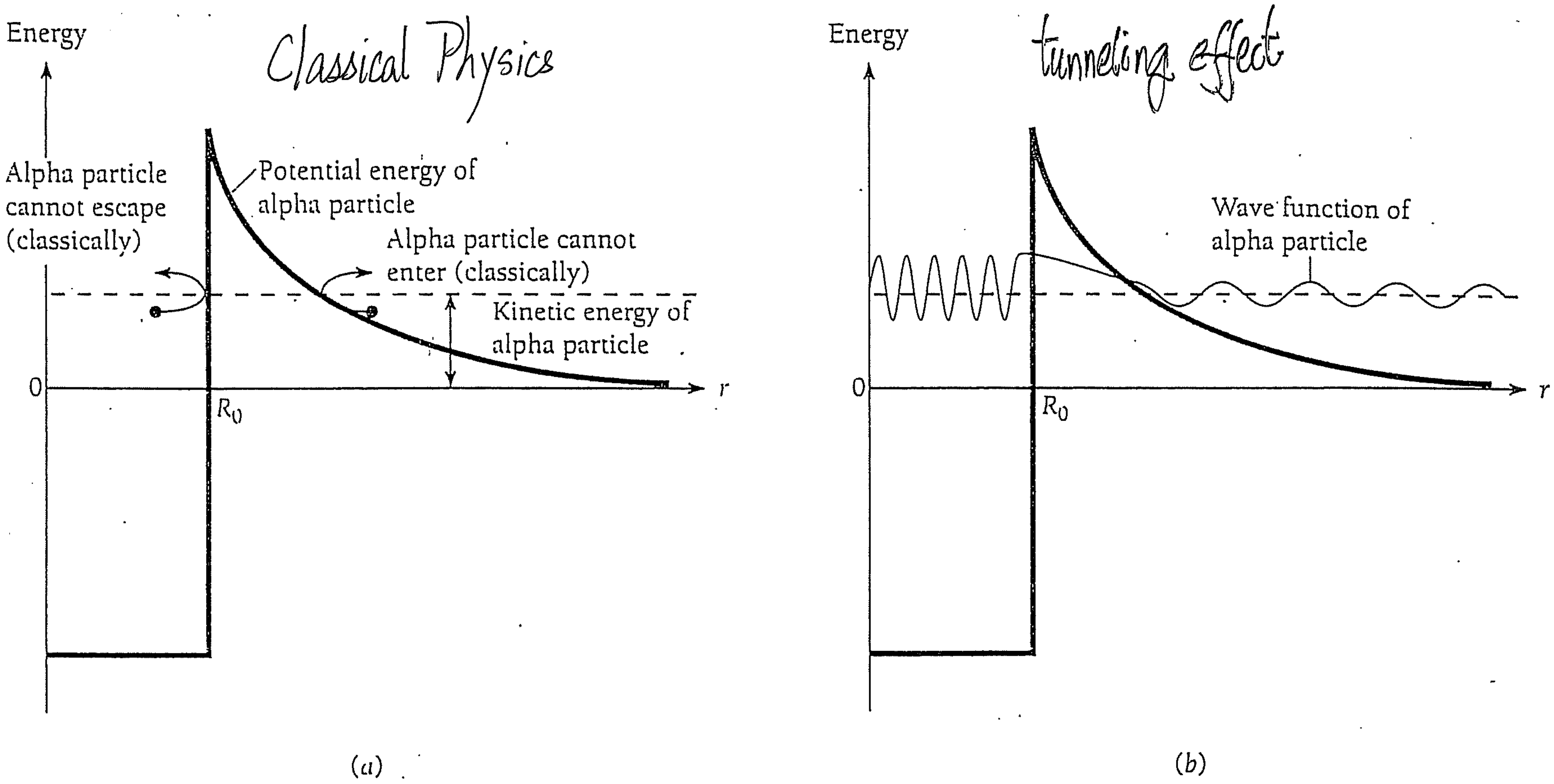
$$\left[P.E. = + \frac{(Z-2)\cdot 2e^2}{4\pi\varepsilon_0 R} \right]$$



due to short-range ($\sim 10^{-15}$ m) nuclear force

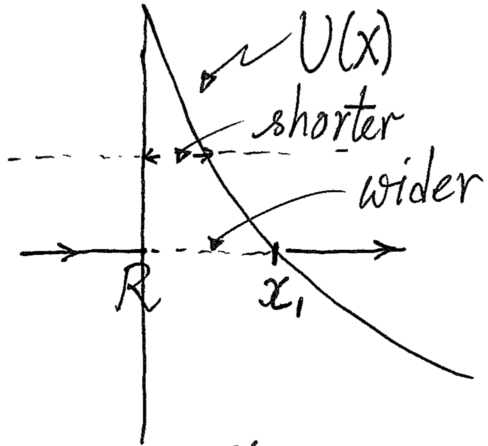
Q: Does α-particle climb out of the barrier?
[No! α-particle k.e. is NOT that high!]

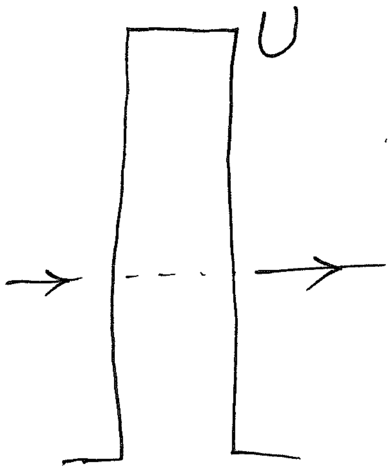
Q: How does α-decay occur? [Tunneling]



(*a*) In classical physics, an alpha particle whose kinetic energy is less than the height of the potential barrier around a nucleus cannot enter or leave the nucleus, whose radius is R_0. (*b*) In quantum physics, such an alpha particle can tunnel through the potential barrier with a probability that decreases with the height and thickness of the barrier.

This is why α-particles (a few MeV) can be detected even the barrier is higher.

but 

instead of 

$$\sim e^{-2\int_R^{x_1}\sqrt{\frac{2m}{\hbar^2}(U(x)-E)}\,dx} \qquad \sim e^{-2L\sqrt{\frac{2m}{\hbar^2}(U-E)}}$$

[slight increase in E changes the value of T by orders of magnitude!]

E.g. $Z = 90$, $E \sim 6\,\text{MeV}$, $R \sim 7\text{-}8\,\text{fm}$ (R = radius of nucleus $\sim A^3$)

↑ mass number (#proton + #neutron)

$T \sim 10^{-29}$ (tiny!)

↑ prob. of getting through per attempt (interpretation)

- So $T \sim e^{-2L\sqrt{\frac{2m}{\hbar^2}(U-E)}}$ is tiny. Why could we see α-decays?
  ↳ prob. of getting through per attempt
- Although T is tiny, α-particle keeps on trying!

  Estimate: Diameter of nucleus = $D \sim 15$ fm (big nucleus)

  α-particle's speed inside nucleus ~ $c/10$ (roughly)

  f = # attempts per second $\sim \dfrac{c/10}{15\text{ fm}} \sim 10^{21}\ s^{-1}$ — try 10^{21} times per second

  ∴ λ = Prob. of a nucleus to decay per second

  (s^{-1}) $= \dfrac{1}{\tau} = T \cdot f$ $\qquad (\tau \cdot \ln 2 = t_{1/2})$

  T: tiny (tunneling); f: a big number (s^{-1}) [keeps on trying]