Radiokrypton Dating Using Atom Trap Trace Analysis

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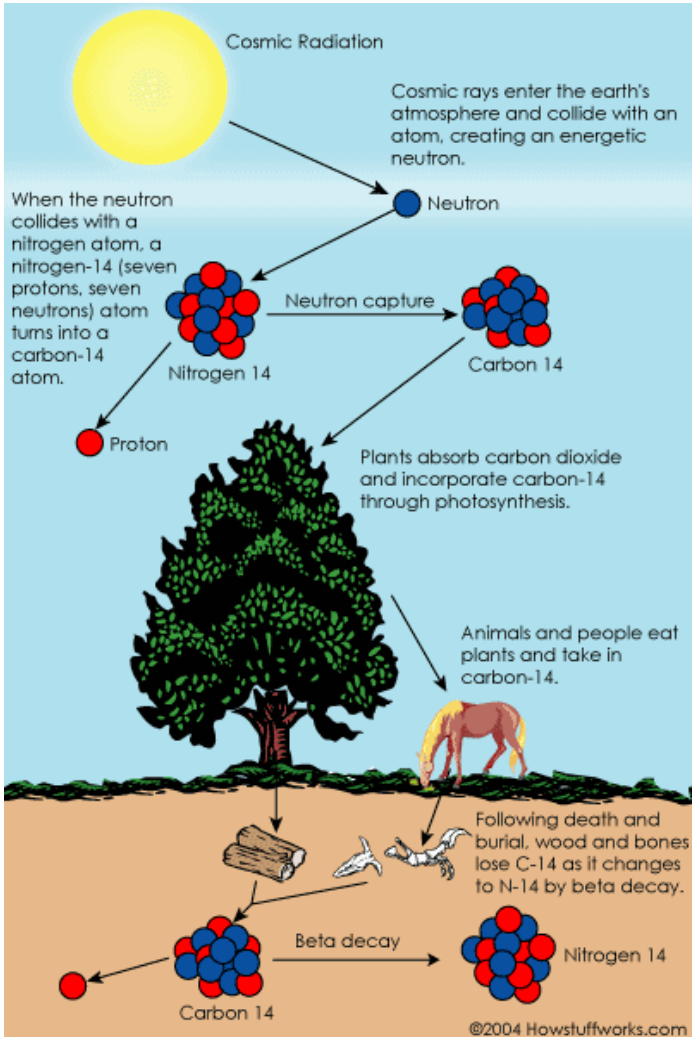
Presentation Outline

- Overview of Radiometric Dating
- Choice of Krypton
- Atom Trap Trace Analysis (ATTA)
  - Advantages
  - Methodology
- Applications

Radiometric Dating

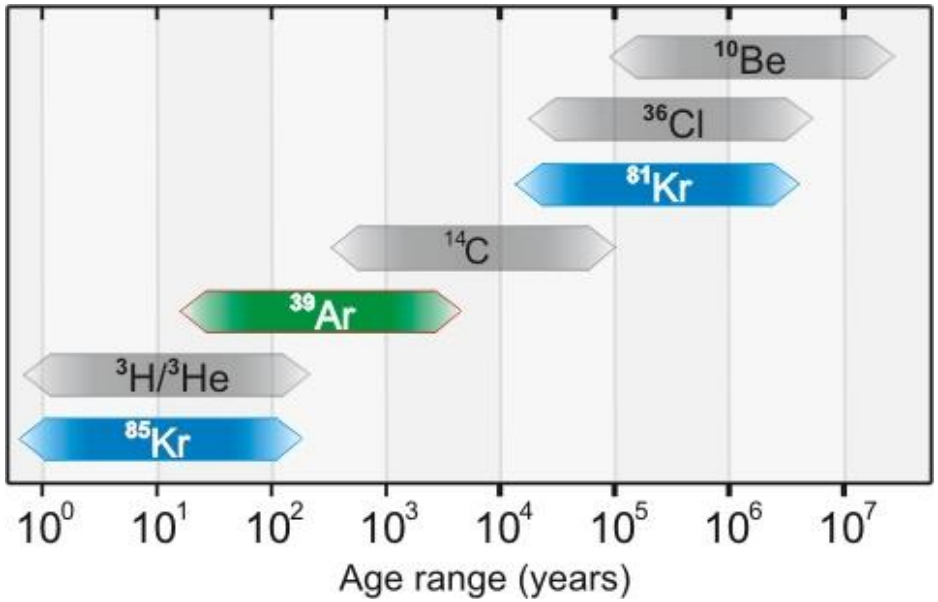
- Closed system (isotopic abundances unchanging)
- Known initial abundance ratios
- Determine final abundance ratios
- Calculate age via decay equations

$$N = N_0 e^{-\lambda t}$$



https://s.hswstatic.com/gif/carbon-14.gif

Suitability of Krypton Isotopes



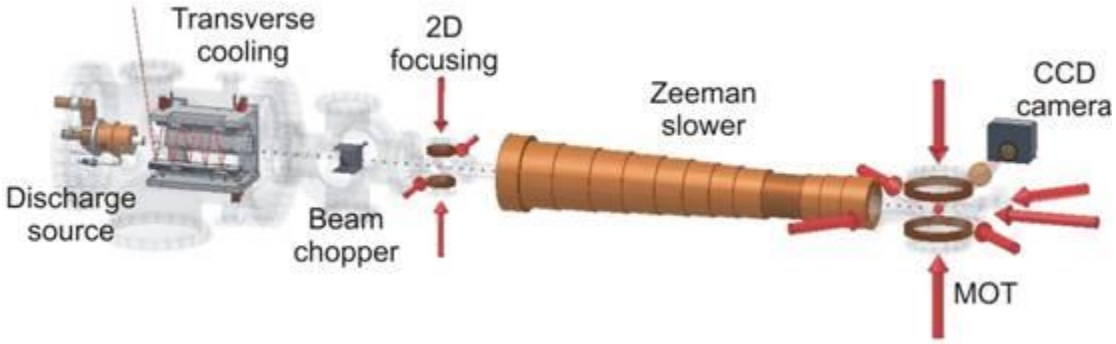
- ^{14}C half life ~ 6000 yrs
- ^{81}Kr
  - Half life ~ 2.3e5 yrs
  - Created similarly to ^{14}C
  - Roughly constant over time
    - » ^{81}Kr/Kr ~ 10e-13
- ^{85}Kr
  - Half life ~ 11 yrs
  - Created via reprocessing of nuclear fission fuels
  - Abundance has increased dramatically since ~ 1950
    - » ^{85}Kr/Kr ~ 10e-11

https://www.phy.anl.gov/mep/atta/research/atta.html

Methods for Radiometric Dating

- Low-Level Counting (LLC)
  - Count individual number of decays
    - » Effective for short-lived ^{85}Kr
    - » Not for long-lived ^{81}Kr
- Accelerator Mass Spectrometry (AMS)
  - Inject a sample into an accelerator
  - Select q/m and E for desired isotope
    - » Good efficiency
    - » Requires an accelerator, and a fairly large sample
- Atom Trap Trace Analysis (ATTA)
  - Trap and count individual atoms
    - » Good efficiency
    - » Tabletop apparatus
    - » Needs a sample ~ 1/10 as large as AMS (50 µl Kr gas vs 500 µl)
    - » Roughly 100 kg of water or 50 kg of ice is required

ATTA Apparatus



- Inject the Kr gas into the apparatus
- Slow the beam using Zeeman slower to < 10 m/s
  - Combination magnetic field and laser set at the resonance frequency
- Trap atoms in the magneto-optical trap (MOT)
- Individual atoms capture and emit photons at the resonance frequency

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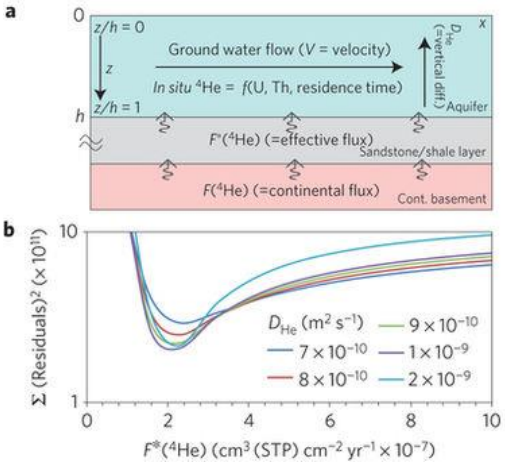
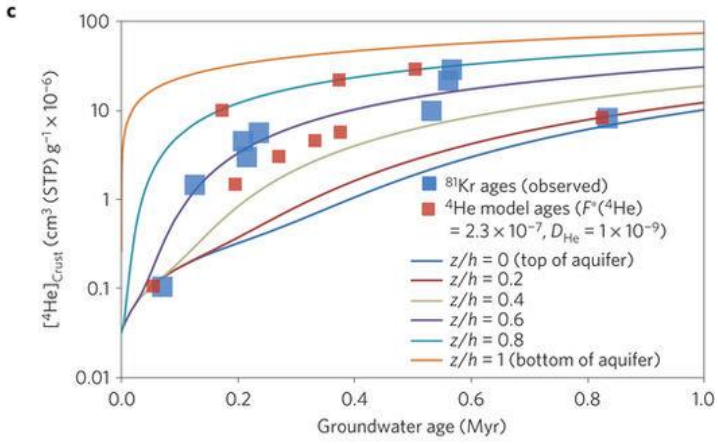
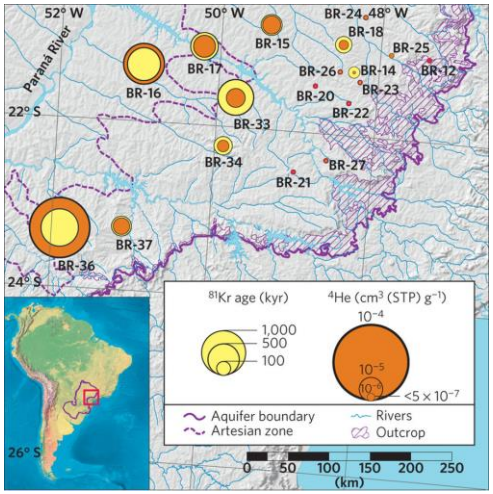
Applications

^{81}Kr

- Climate analysis
  - Polar ice
- Aquifer studies
  - ^{4}He degassing
- Geothermal activity
  - Yellowstone







^{85}Kr

- Dating young groundwater
- Tracer for ocean currents

Final Thoughts

- Radiometric dating is a really interesting field with many applications
- ATTA is an excellent machine for such work

- Thanks to Prof. Nazarewicz, and Tong Li
- Questions?

References

- https://arxiv.org/ftp/physics/papers/0311/0311118.pdf
- http://www.phy.anl.gov/mep/atta/research/atta.html
- http://www.phy.anl.gov/mep/atta/research/atta_applications.html
- http://www.pnas.org/content/111/19/6876
- https://www-nature-com.proxy1.cl.msu.edu/articles/ngeo2302