Principles of radioactive decay - Clues from isotopes

- "Chemical element"
  specified by # of electrons in the neutral atom
  = atomic number (Z)
- Example: Rubidium (Rb) has 37 electrons. Z=37

Review : Isotopes

- **Isotopes are atoms that have the same atomic number Z but difference atomic weights (A)**
- **Review: Hydrogen has 3 isotopes**
  1) **H^1 Hydrogen 1 p 0 n 1e**
  2) **H^2 Deuterium 1 p 1 n 1e**
  3) **H^3 Tritium 1 p 2 n 1e**

Example two: Rubidium

- Rubidium has 2 common isotopes

	# e	#p	#n
A	Z	Z	(A-Z)
Rb^{85}	37(-)	37(+)	48
Rb^{87}	37(-)	37(+)	50

Rubidium 87 is radioactive

- **Decays spontaneously into Sr^{87} (strontium) with a half-life of 47 billion years:**

$$Rb^{87} \rightarrow Sr^{87} \quad (t_{1/2} = 47 \times 10^{9}\ \text{yr})$$

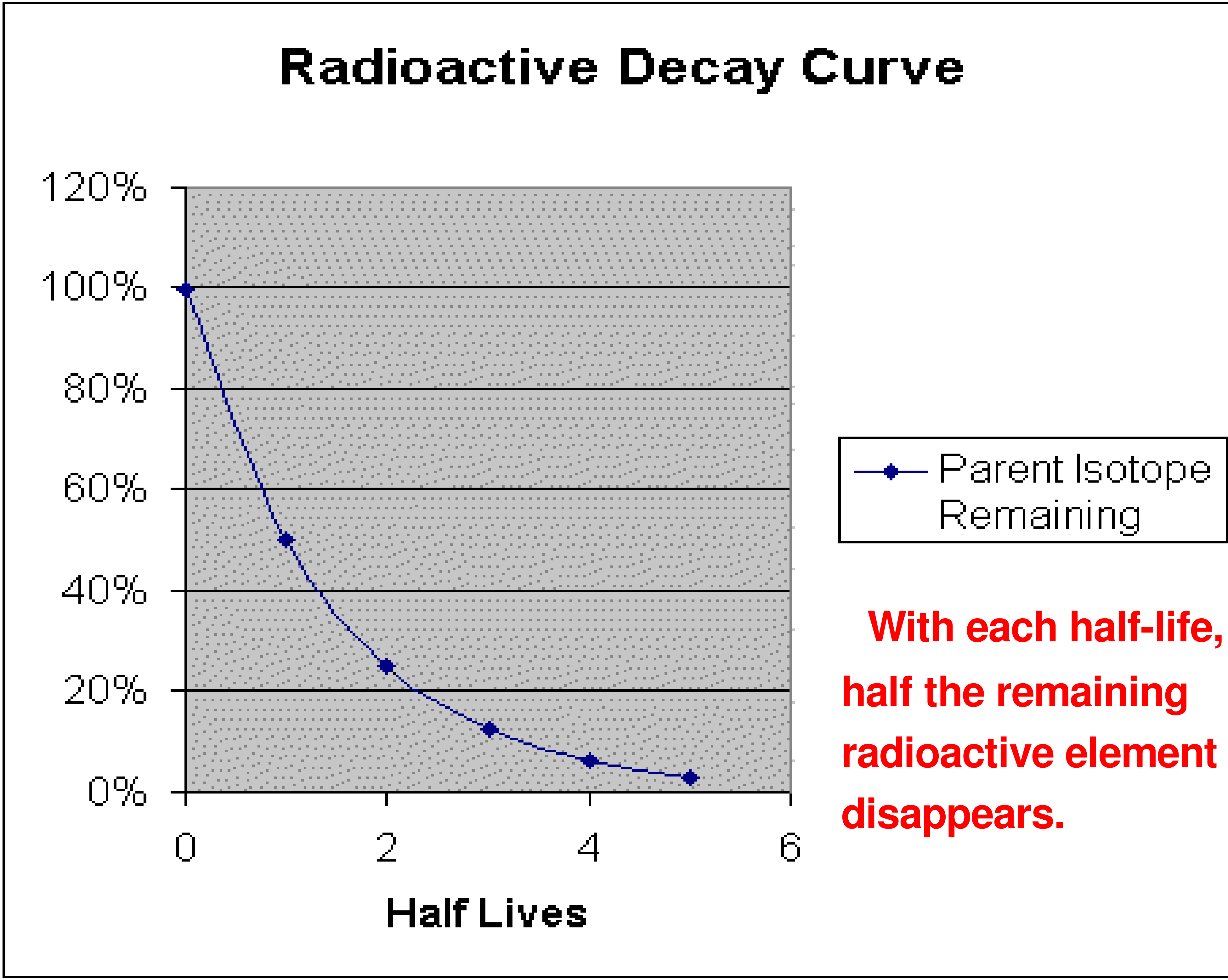
What does half-life mean?

Radioactive half-life

- **Decays spontaneously into Sr^{87} (strontium) with a half-life of 47 billion years:**

Rb^{87}-->Sr^{87} ($t_{1/2}$ = 47 x 10^9 yr)

What does half-life mean?
If we start with N atoms of Rb^{87} at time t=0, after 47 Gyr there will be N/2 left.


Radioactive Decay Curve
120%
100%
80%
60%
40%
20%
0%
0
2
4
6
Half Lives
Parent Isotope Remaining
With each half-life, half the remaining radioactive element disappears.

Parent-daughter

- **In this decay:**

$Rb^{87} \rightarrow Sr^{87}$ ($t_{1/2} = 47 \times 10^9$ yr)

Rb^{87} is called the *parent* isotope

Sr^{87} is called the *daughter* isotope

The daughter isotope abundance *increases* with time.

Chronology: minerals

Rb^{87}-->Sr^{87} (unstable)

Sr^{87} is STABLE (doesn't decay).
How can we use this?

When rocks condense, they contain specific minerals, some of which incorporate Rb and Sr : this process ignores the isotope. i.e., will incorporate as much Rb^{87} (unstable)
as Rb^{86} (stable).

Subsequent decay

- **So some minerals contain more Rb than others.**
- **The Rb^{87} decays to Sr^{87}**
- **If we could measure Sr^{87} in one of these minerals , could we know how long ago the rock formed?**
- **NO: for two reasons**

2 practical problems

- There may often be some initial daughter element!
- Measurements of abundance of a single isotope very difficult. But one can measure RATIOS very very accurately.

The trick to absolute isotopic cosmochronology
(besides spelling it!)

- **Divide by the abundance of another isotope of the daughter element:**

  Rb^{87}-->Sr^{87}; use Sr^{86} as reference

  So measure the ratios :

  Sr^{87}/Sr^{86} and Rb^{87}/Sr^{86}

  with mass spectroscopy

  (transparancy)

Isotopic evolution from radioactive decay produces an isochrone

- Slope of plot of (Sr^{87}/Sr^{86}) versus (Rb^{87}/Sr^{86}) gives (see transparency):
  - Time since rock solidified
    - If system has been 'closed'
  - Initial abundance of daughter element (see transparancy)

Have to measure several minerals.

Rb/Sr dating of meteorites

- **All primitive chondrites give ages of 4.5 +/- 0.1 Gyr.**
  - **Some of the best are 4.54 +/- 0.05 Gyr**
- **Contrast: Oldest rocks on Earth about 3 Gyr old (why? Is Earth 3 Gyr old?)**
- **Oldest rocks on moon ~4.3 Gyr old**

Chondrites date the 'age of the Solar System'

I/Xe isotopic system

- **Iodine 129 decays spontaneously (into Xenon 129) with a half-life of 17 million years:**

$$I^{129} \text{-->} Xe^{129} \quad (t_{1/2} = 17 \times 10^6 \text{ yr})$$

But Xe is a noble gas, so it wouldn't be normally found in rocks???

I/Xe isotopic system

- **Solution: Iodine must have been incorporated into some rocks and then decayed into Xe. The Xe could not escape ('trapped') IF the rock was cool (<600 K).**
- **Consequence: The Xe^{129} can be measured and tell us how long it took the 'parent body' to cool.**

What do measurements say?

Meteoritic 'Parent Body' cooling times

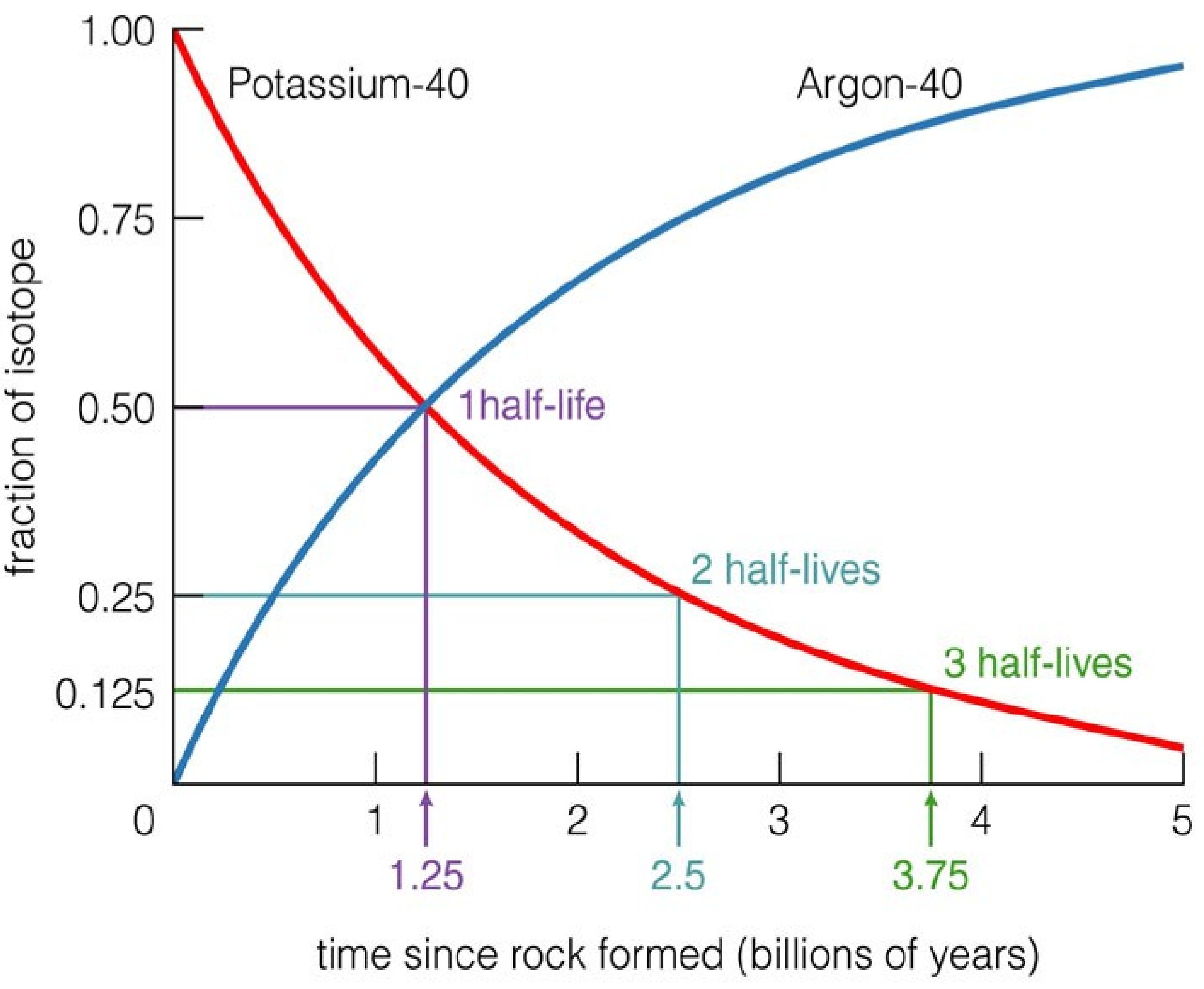
- Answer: Parent bodies typically took 10-100 Myr to cool
    - Most chondrites: ~20 Myr
    - Achondrites/irons: ~100 Myr
- So differentiated parent bodies (measured from achondrite stones) took longer to cool.

Reasonable!

Important implication: Differentiated PBs formed (accretion + melting + cooling) in <100 Myr and *never reheated* (why?)

K-Ar system

- Potassium 40 decays into Argon 40
- Argon 40 escapes from warm rocks



Presence of Argon 40 dates the `cooling age' of the rock.

Some lunar rocks 4.4 Gyr old --> Moon formed early.