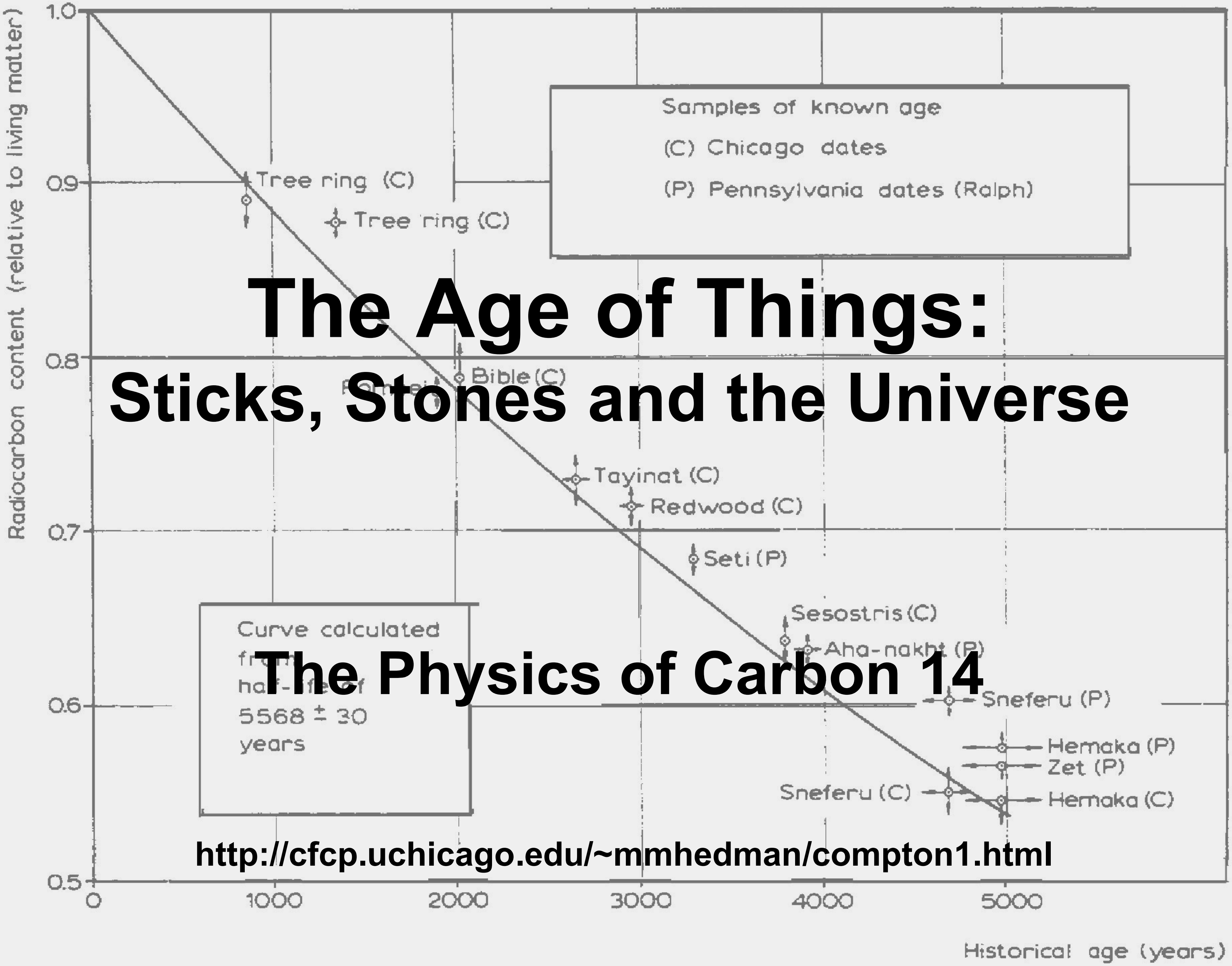
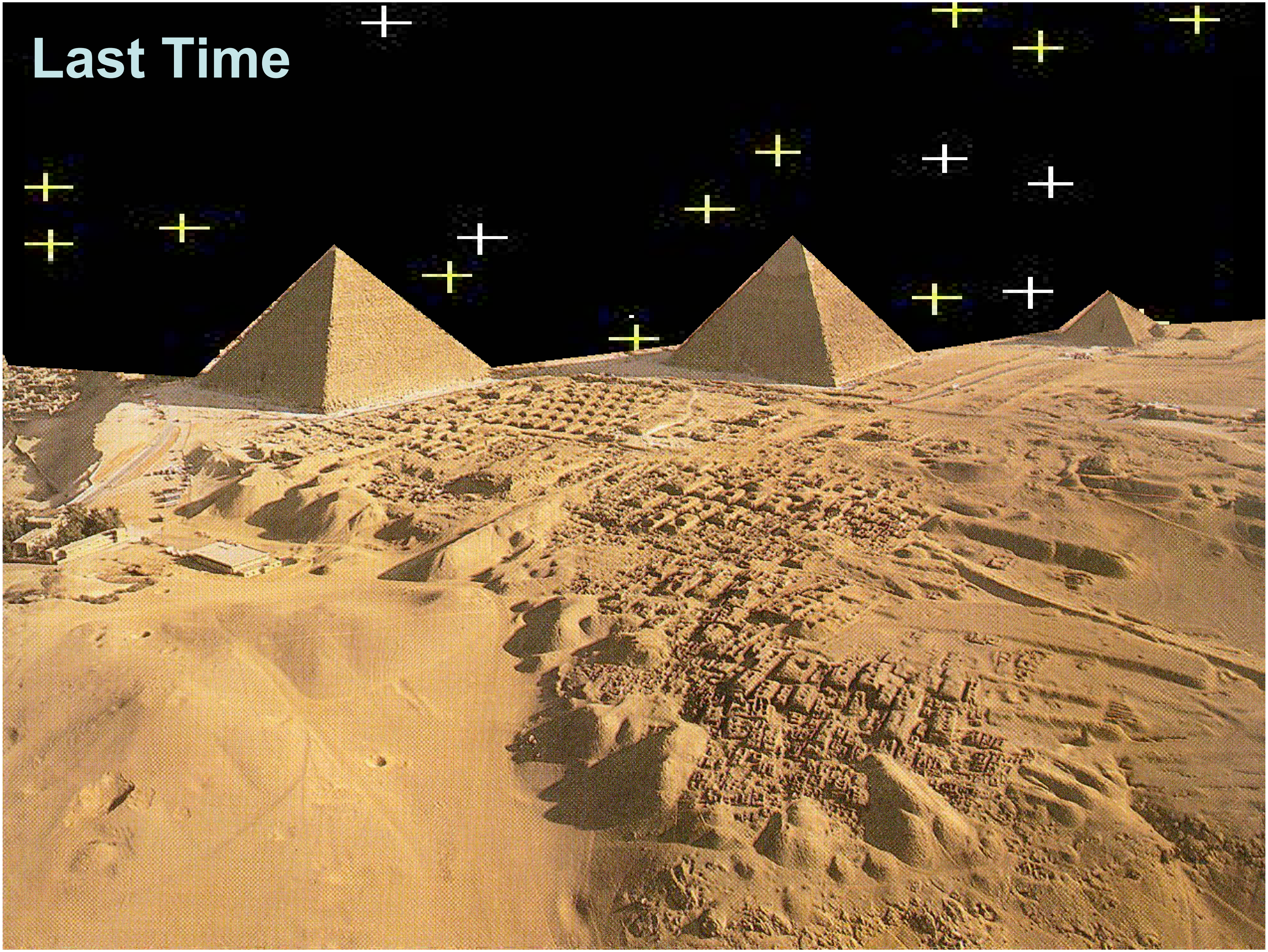
The Age of Things:

Sticks, Stones and the Universe

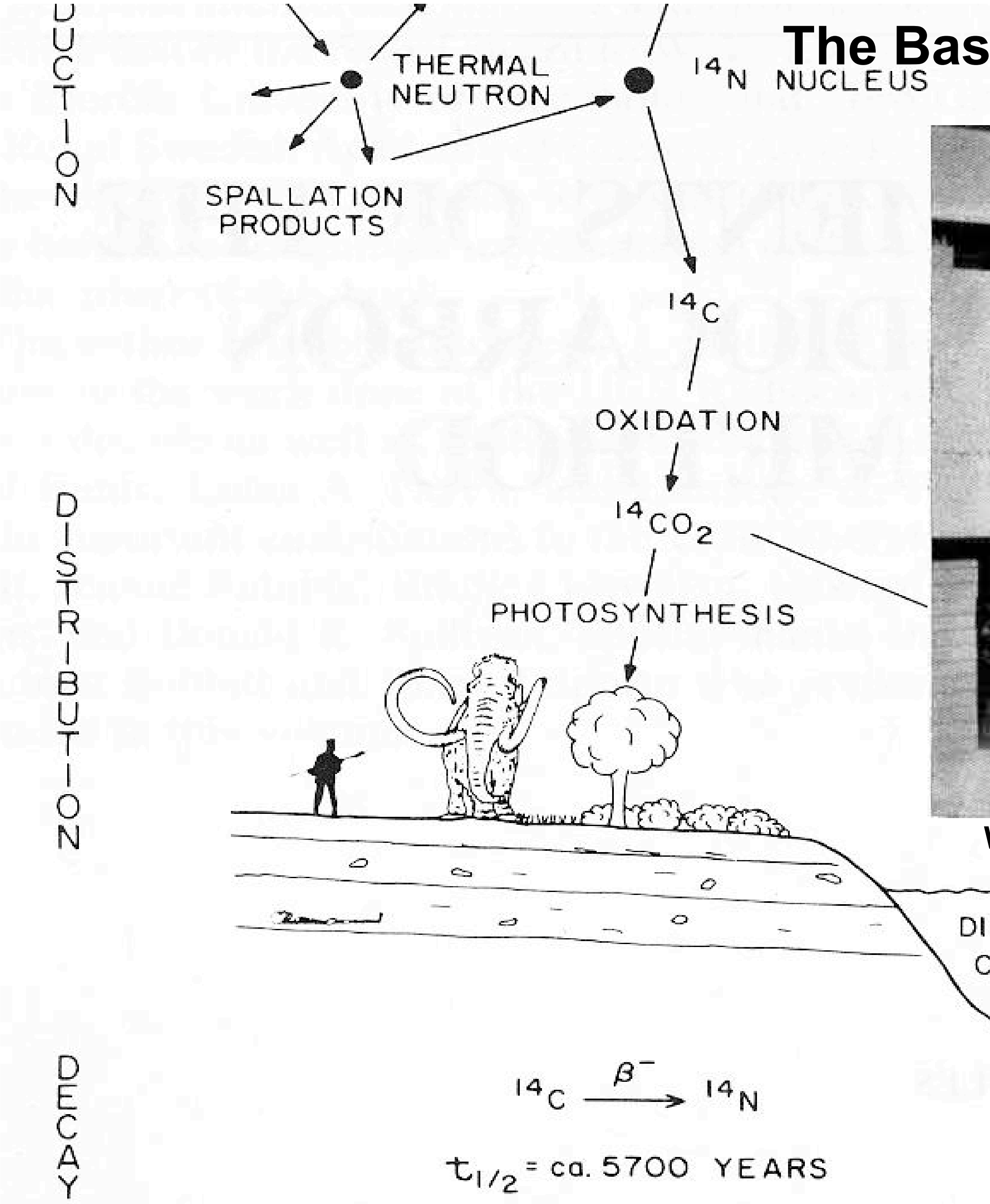
The Physics of Carbon 14

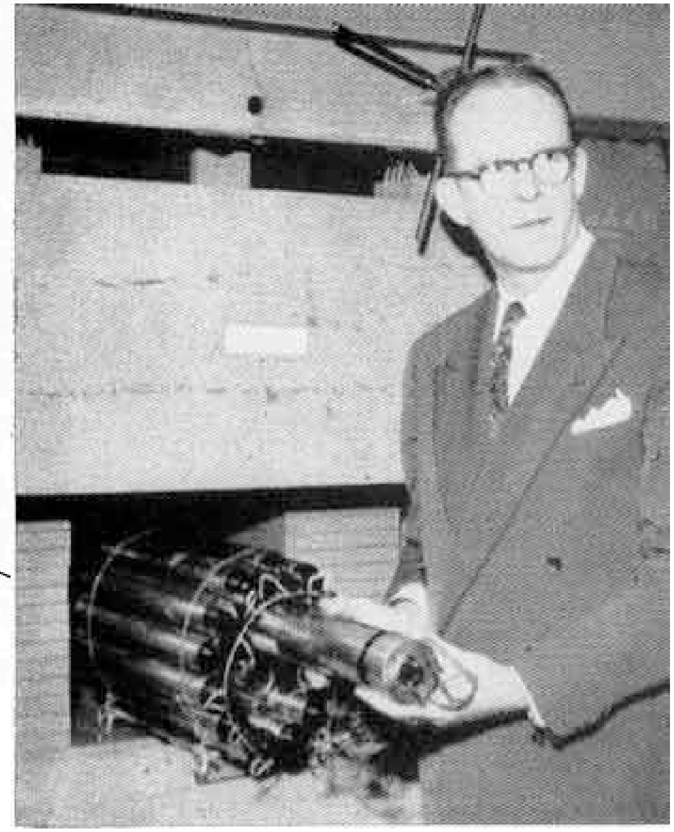


http://cfcp.uchicago.edu/~mmhedman/compton1.html


Last Time

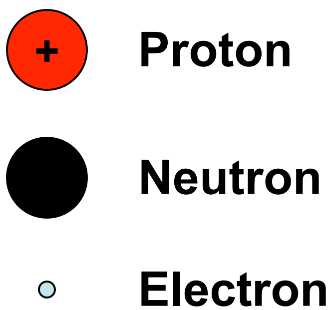
The Basic Idea of Carbon 14





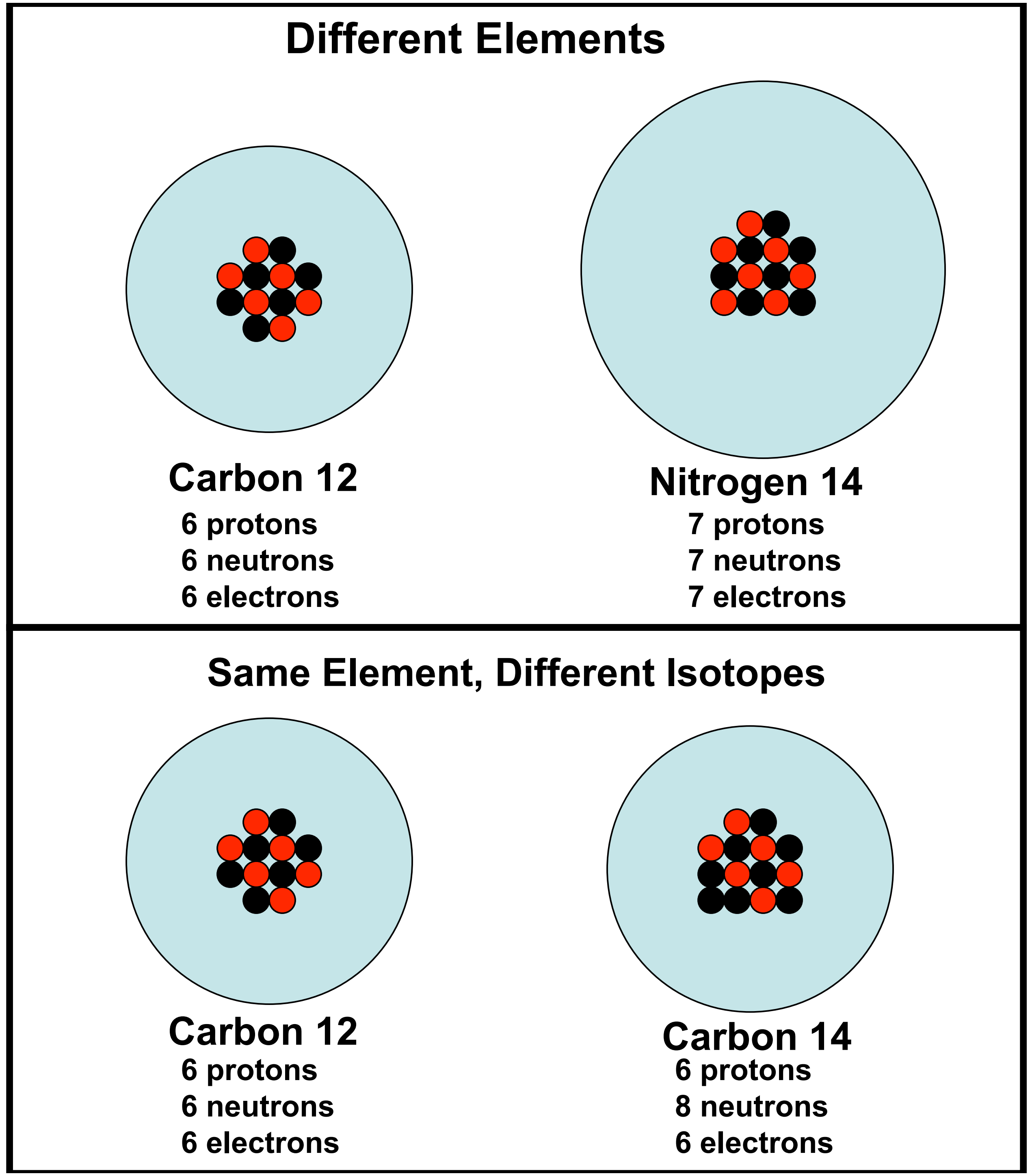
Willard F. Libby, inventor of Carbon-14 Dating

Nomenclature

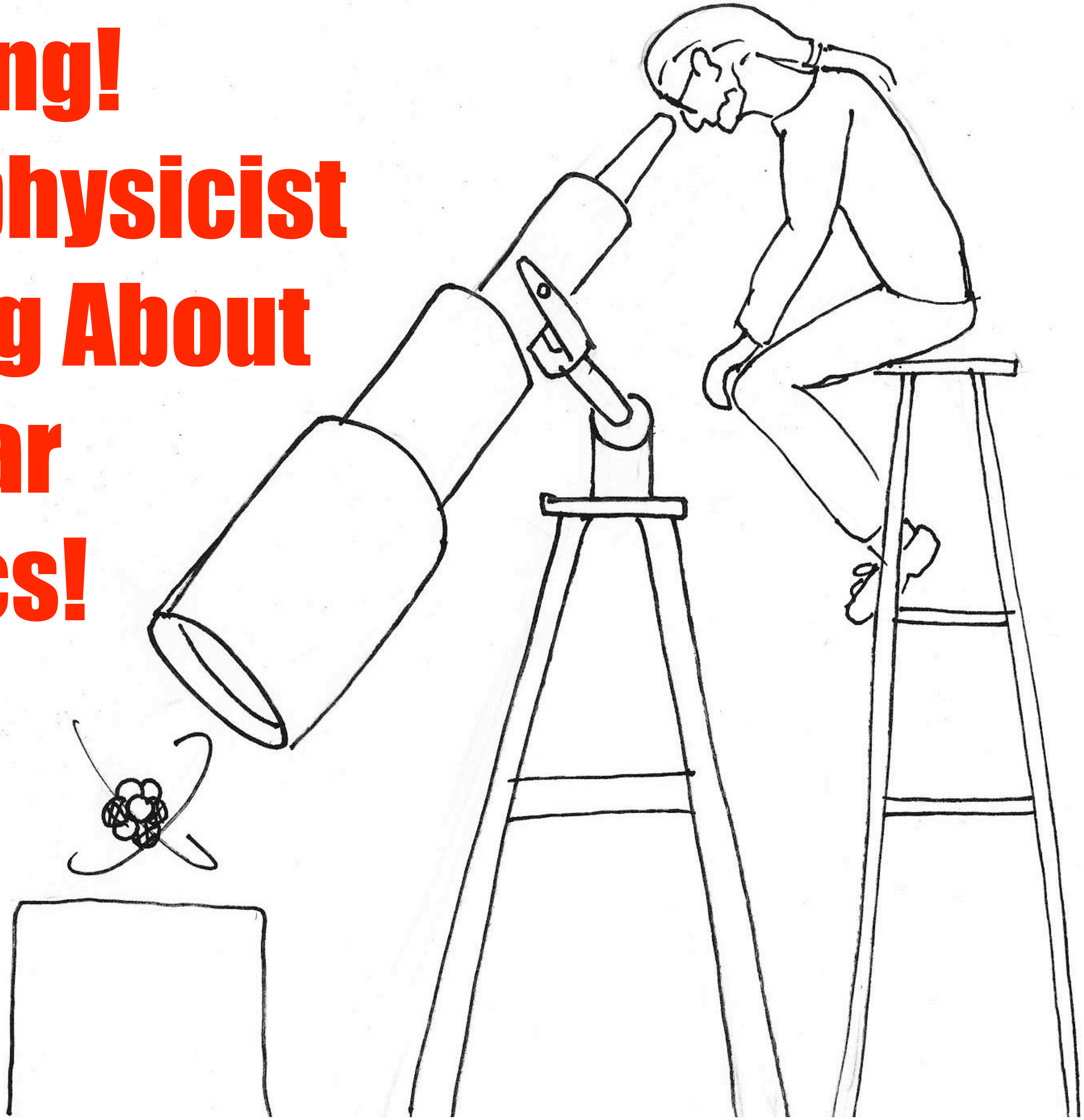


Element:
Number of Protons

Isotope:
Number of Neutrons
(Same No. of Protons)



Warning! Astrophysicist Talking About Nuclear Physics!



Why are nuclei stable? Because….

$$E = m\,c^2$$

Just a number

Energy

Mass

Any object with mass also contains a certain amount of energy

Why are nuclei stable? Because….

$$E = m\,c^2$$

Energy

Just a number

Mass:

Intrinsic quality of an object

Determines how the object moves in response to forced

Same Push

More Mass → Less Motion

Less Mass → More Motion

Why are nuclei stable? Because….

$$E = m\,c^2$$

Just a number

Energy:

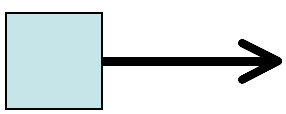
A conserved quantity
(energy can change form,
but not be created or destroyed)

The potential to cause motion

Mass:

Intrinsic quality of an object

Determines how the object
moves in response to forced



Less velocity, less Kinetic Energy

More velocity, more Kinetic Energy

Why are nuclei stable? Because….

$$E = m\,c^2$$

Just a number

Energy:

A conserved quantity
(energy can change form,
but not be created or destroyed)

The potential to cause motion

Mass:

Intrinsic quality of an object

Determines how the object
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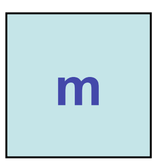
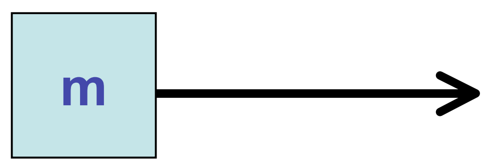
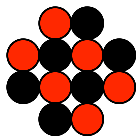


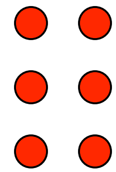
Energy = E

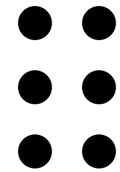


Energy = E + *E*

Nuclear Stability

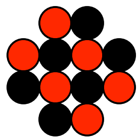






Mass of Carbon-12 $<$ Mass of 6 protons + Mass of 6 Neutrons

Nuclear Stability



Mass of Carbon-12 < Mass of 6 protons + Mass of 6 Neutrons

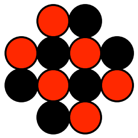
Since $E = m c^2$……

Energy of Carbon-12 < Energy of 6 protons + Energy of 6 Neutrons

So, energy must be supplied to the nucleus to break it into its component parts. The nucleus cannot break apart on its own.

A nucleus can only only decay if the products of the decay have less mass than the original nucleus

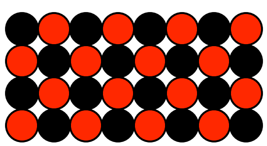
Nuclear Stability

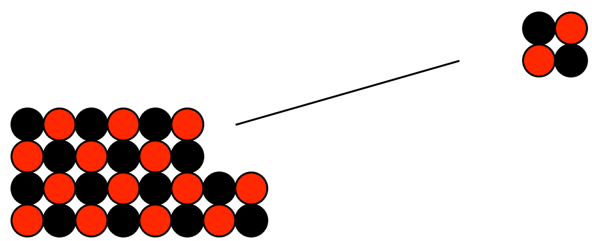


Mass of Carbon-12 < Mass of 6 protons + Mass of 6 Neutrons

Since $E = m c^2$......

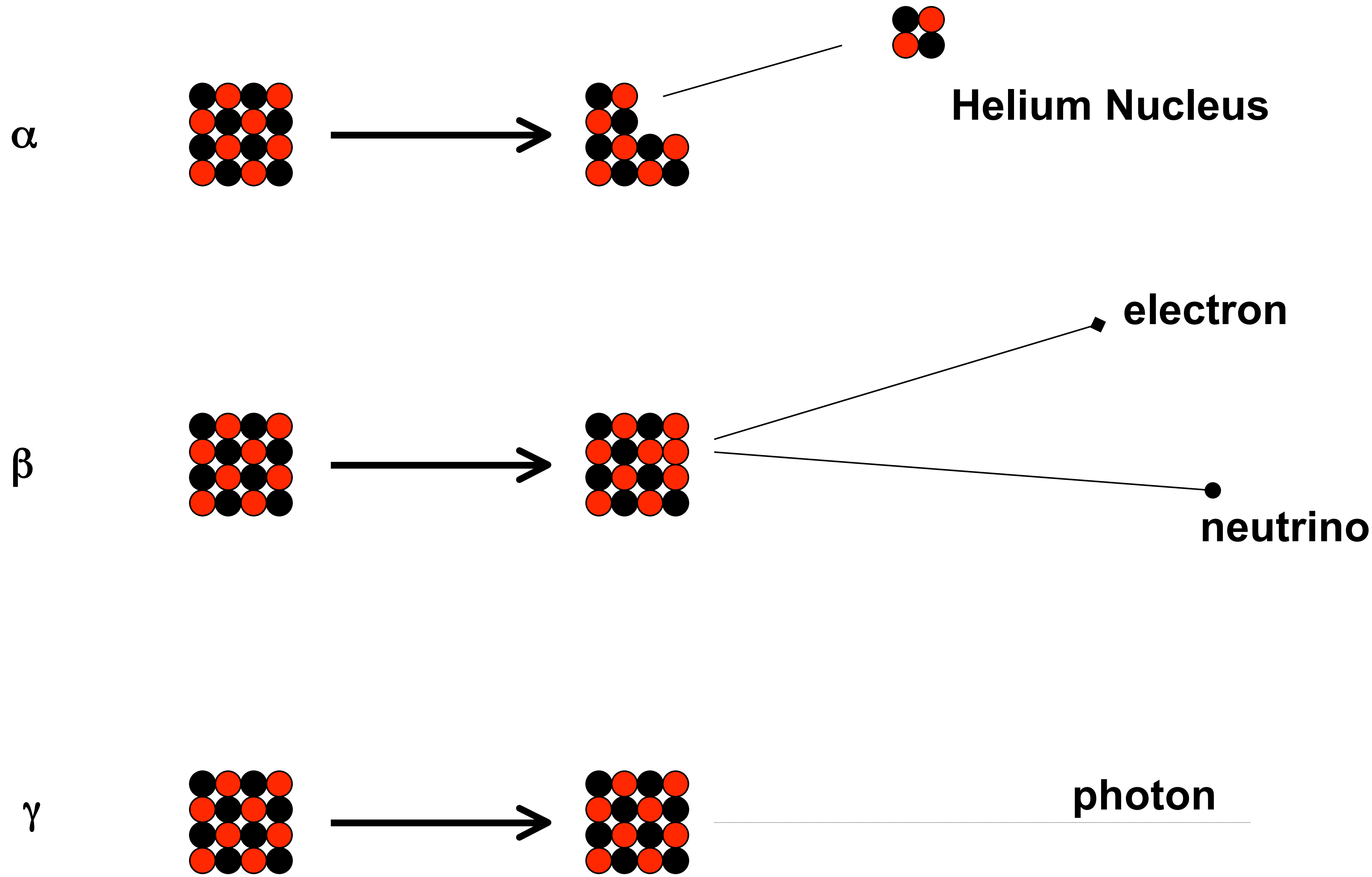
Energy of Carbon-12 < Energy of 6 protons + Energy of 6 Neutrons



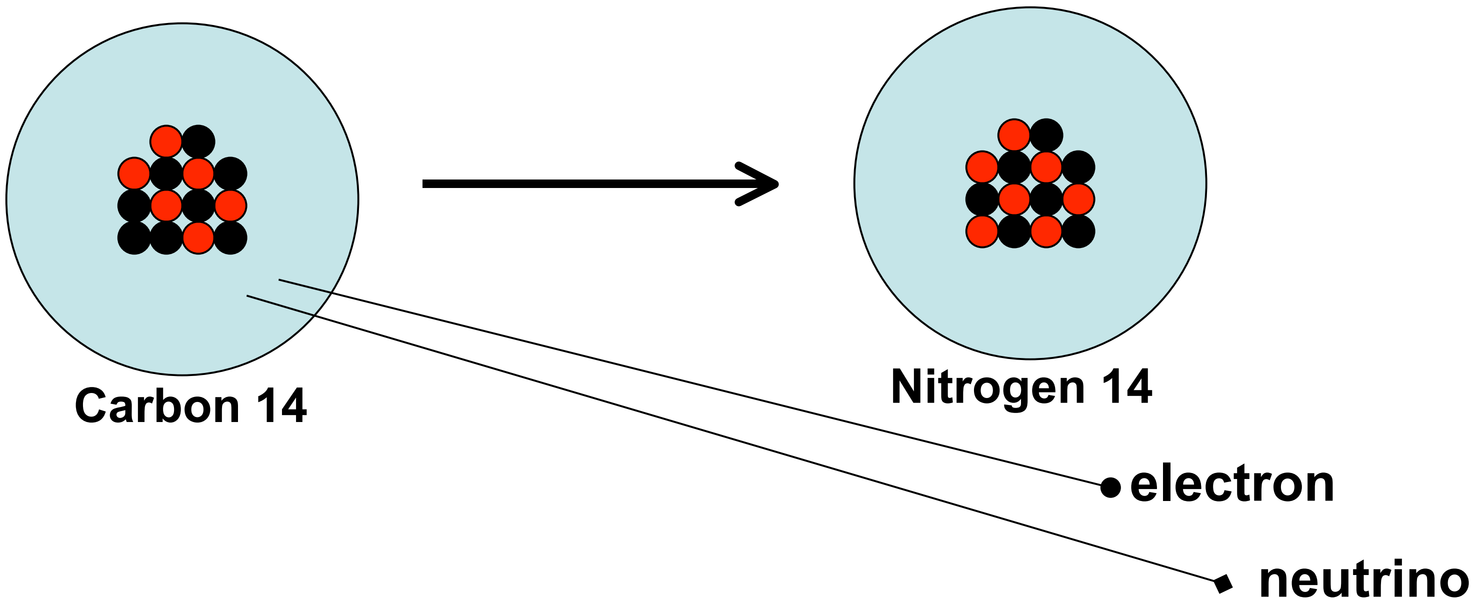


Mass of Initial State > Mass of Final State

Three Types of Nuclear Decay



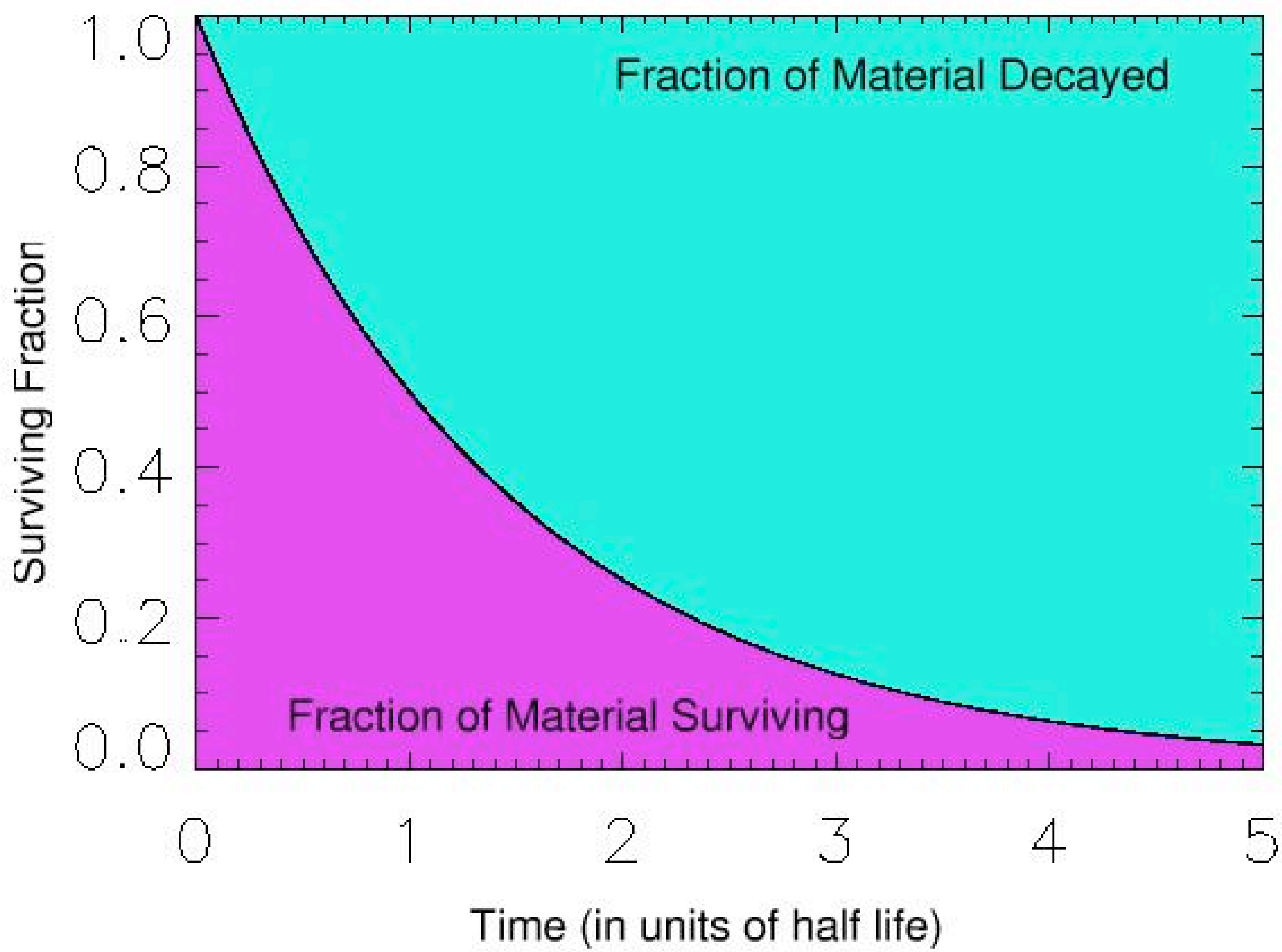
Carbon 14 Decay



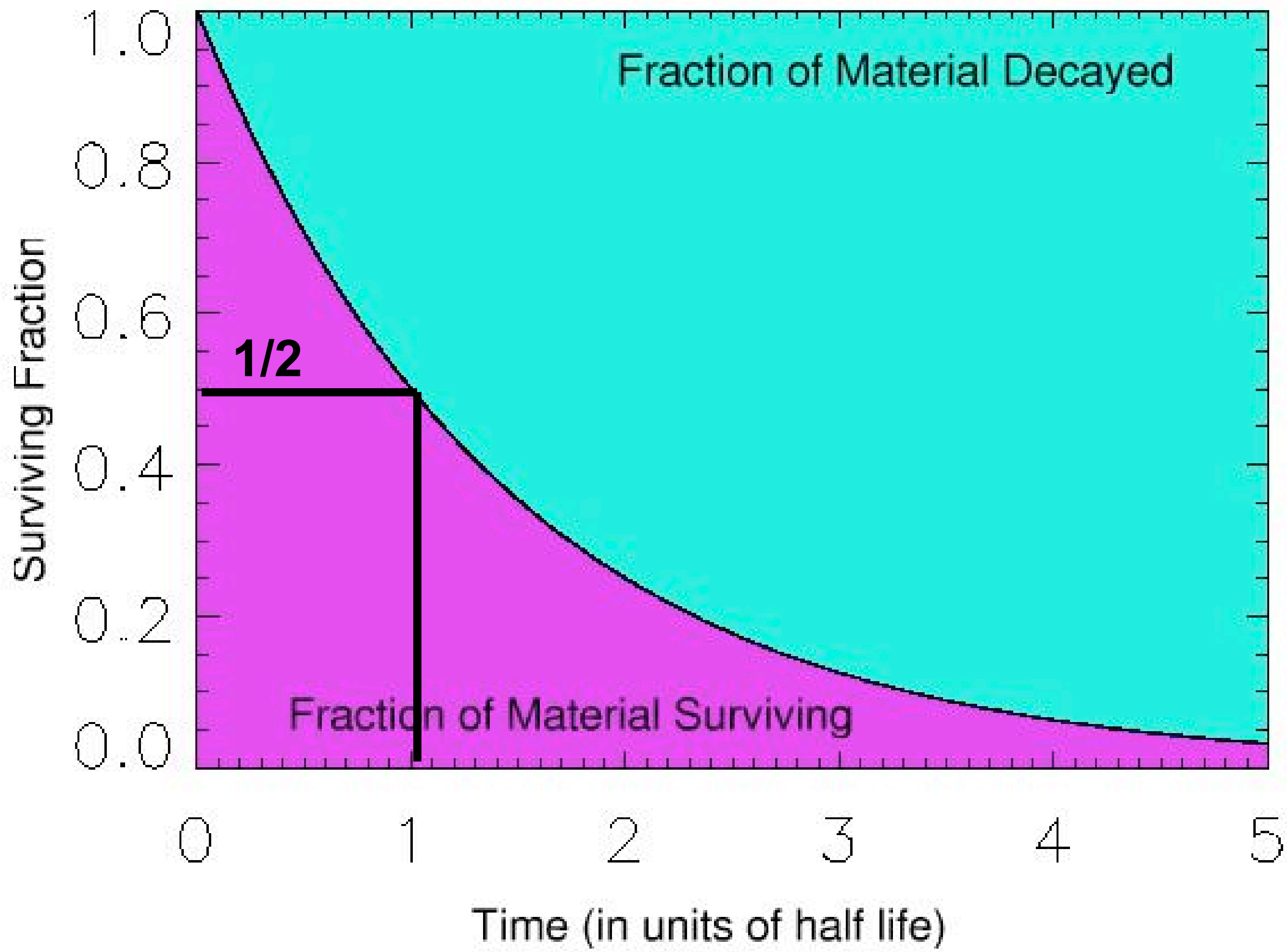
This is an allowed transformation (beta-decay)

Mass of Carbon 14 > Mass of Nitrogen 14 etc.
so the transformation can occur without
an external source of energy

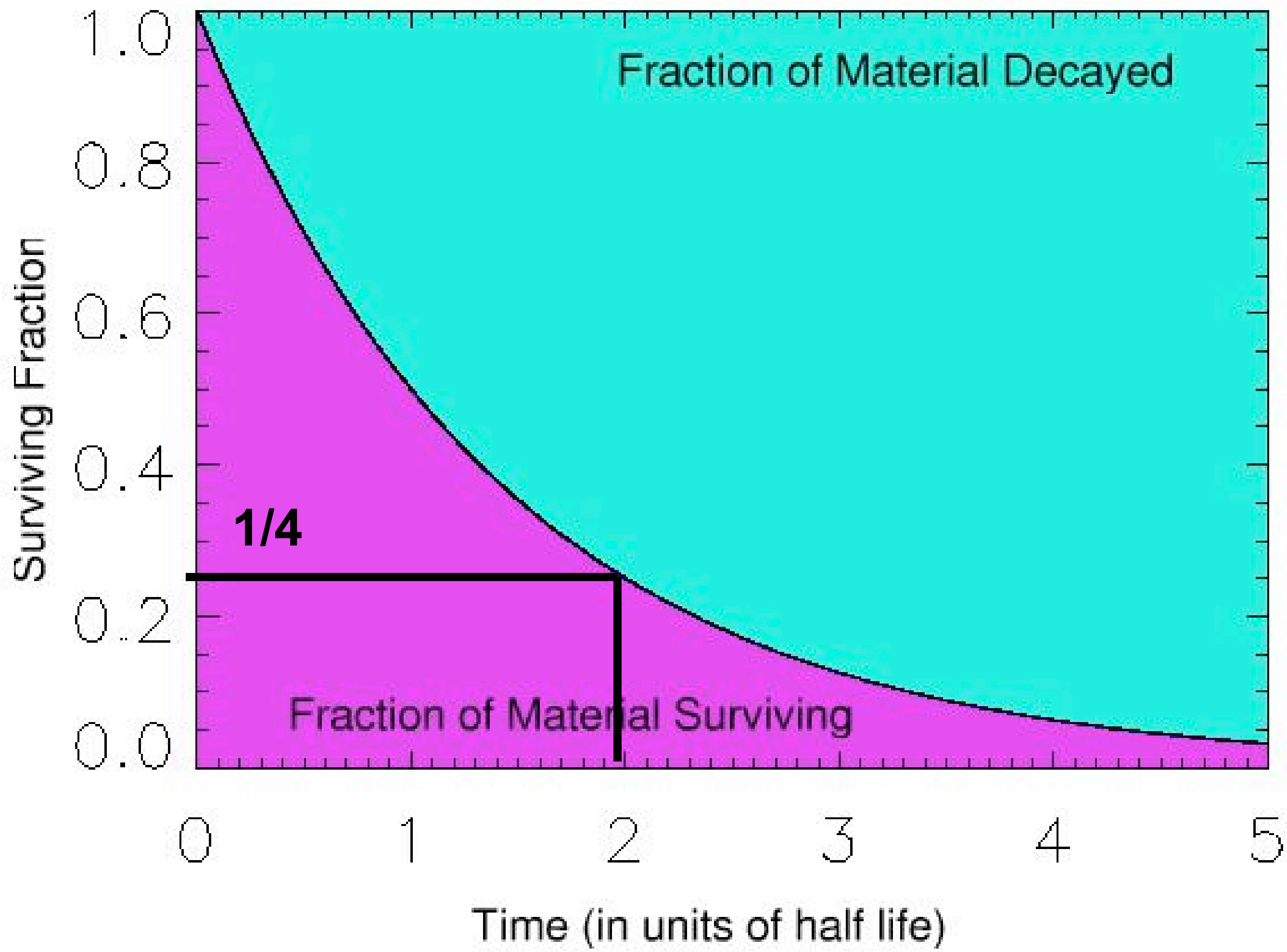
Half-Life


Fraction of Material Decayed
Fraction of Material Surviving
Surviving Fraction
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
Time (in units of half life)

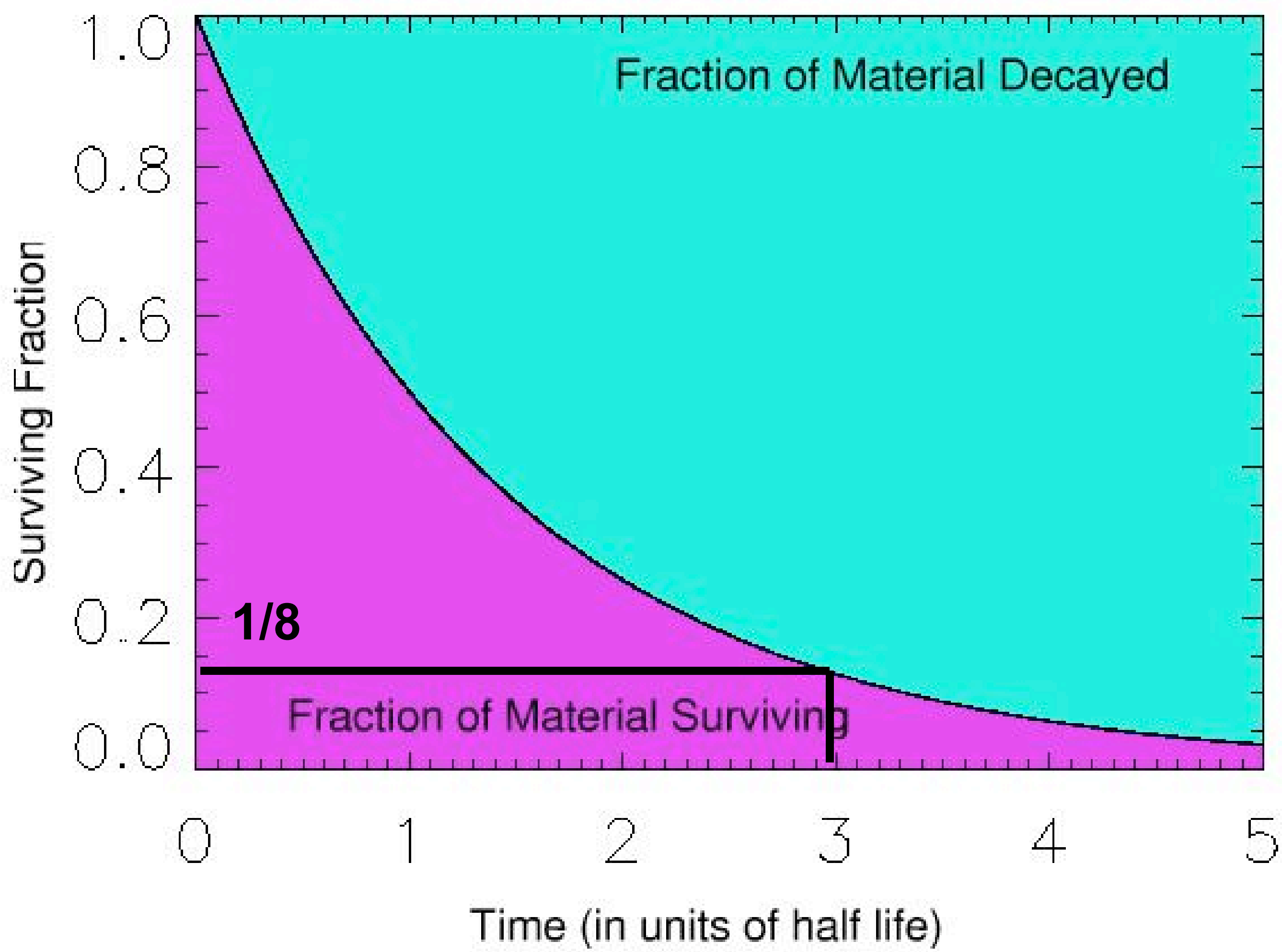
Half-Life


Fraction of Material Decayed
Fraction of Material Surviving
1/2
1.0
0.8
0.6
0.4
0.2
0.0
Surviving Fraction
0
1
2
3
4
5
Time (in units of half life)

Half-Life

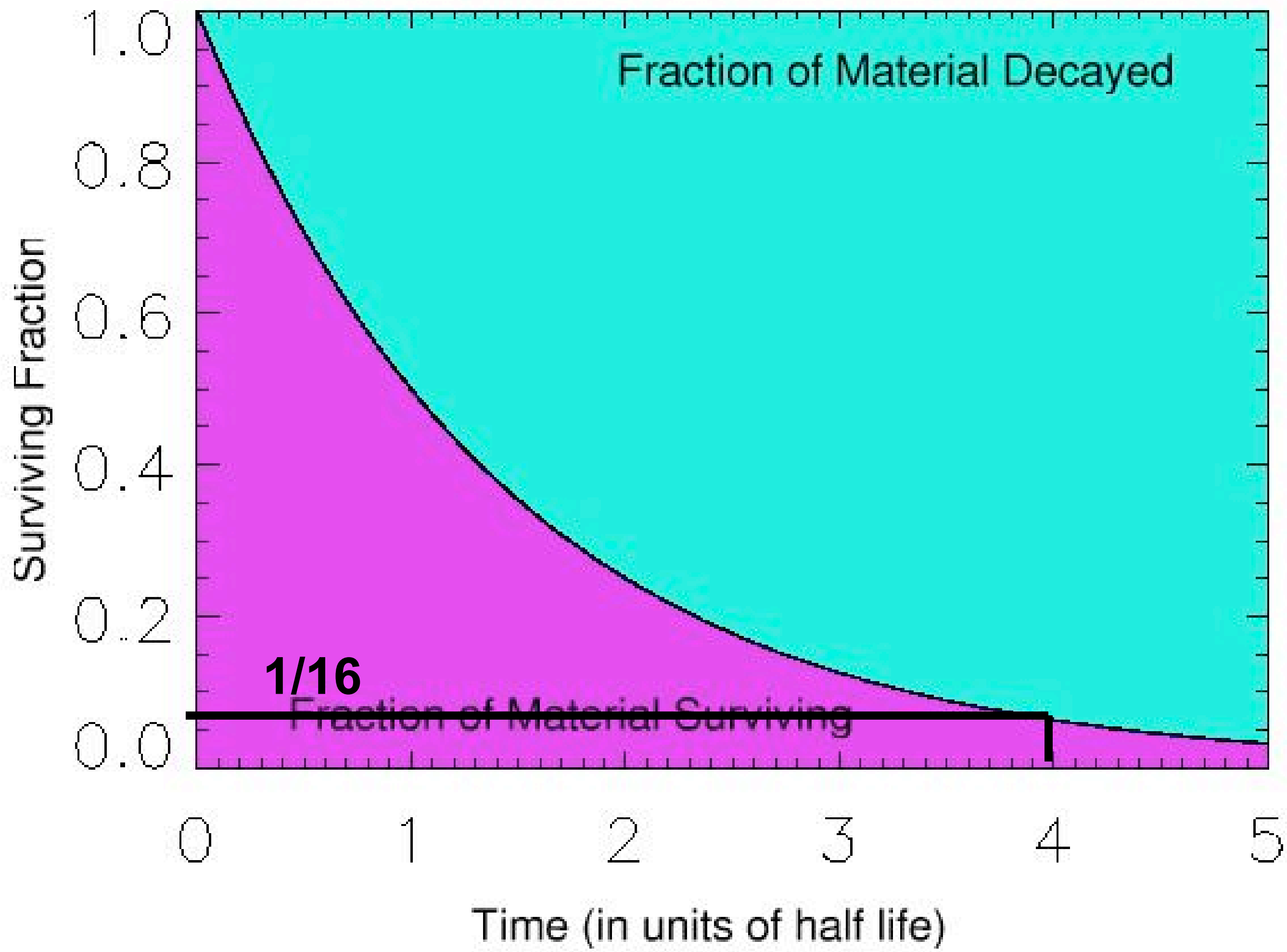

1.0
0.8
0.6
0.4
0.2
0.0
Surviving Fraction
Fraction of Material Decayed
1/4
Fraction of Material Surviving
0
1
2
3
4
5
Time (in units of half life)

Half-Life



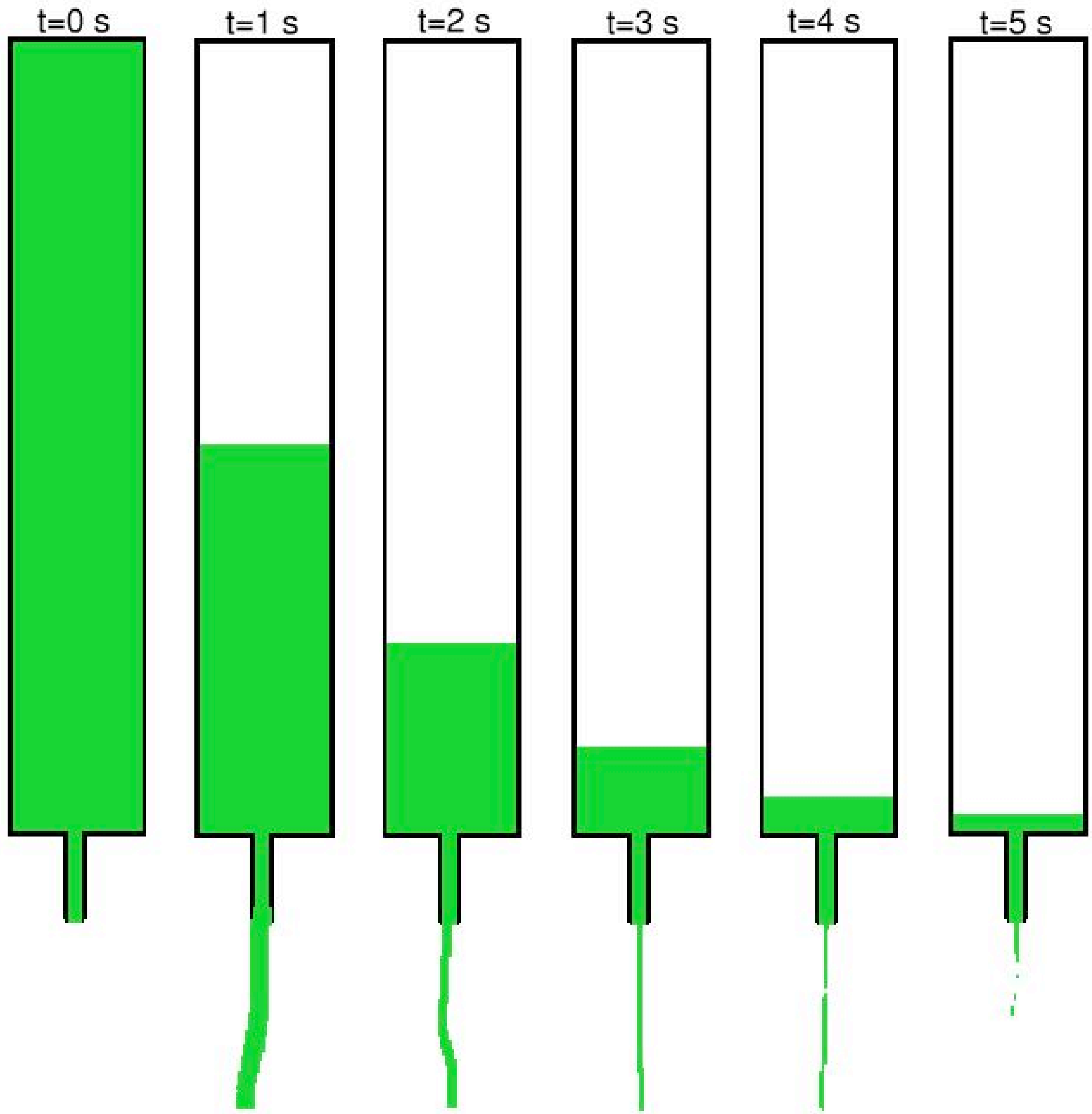
Fraction of Material Decayed
Fraction of Material Surviving
1/8
Surviving Fraction
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
Time (in units of half life)

Half-Life

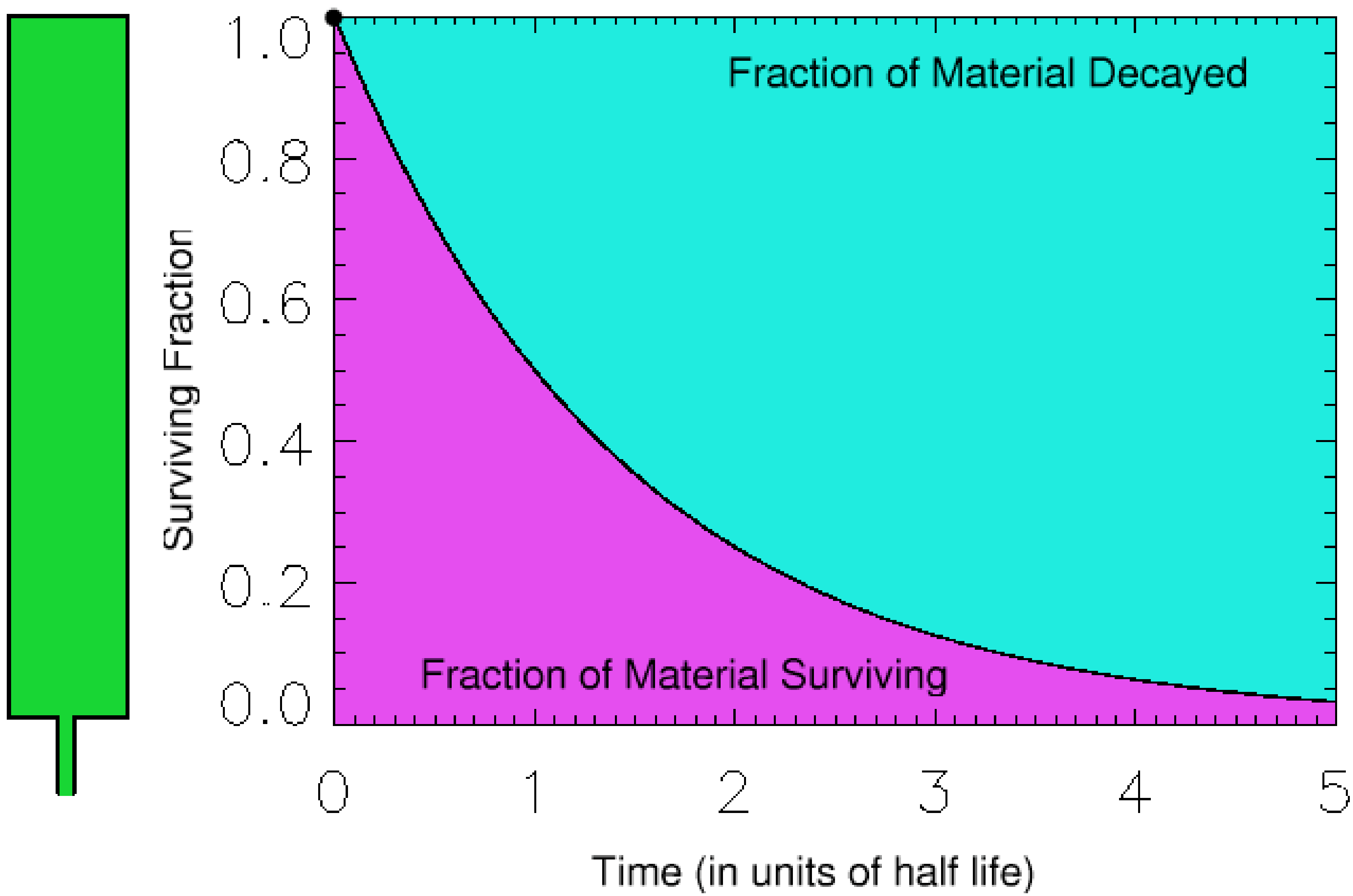


Fraction of Material Decayed
1/16
Fraction of Material Surviving
Surviving Fraction
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
Time (in units of half life)

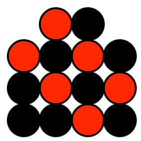
Another system with a half-life



Another System with a Half-life

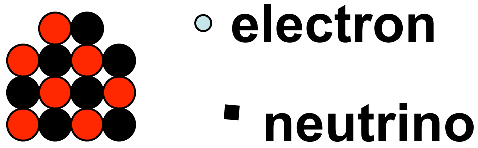


A nucleus can only exist in two definite forms



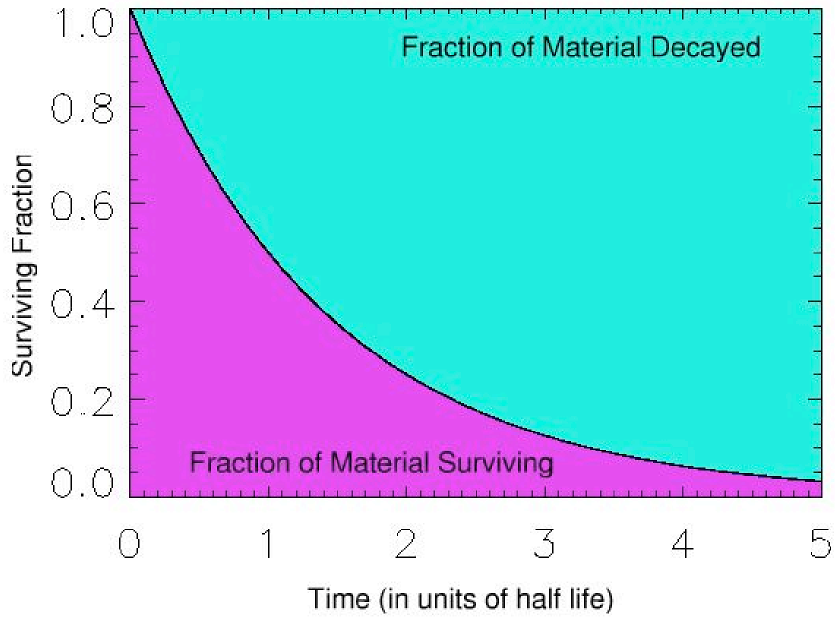
Carbon 14

OR



Nitrogen 14

The probability the nucleus is in one of these forms has a half-life



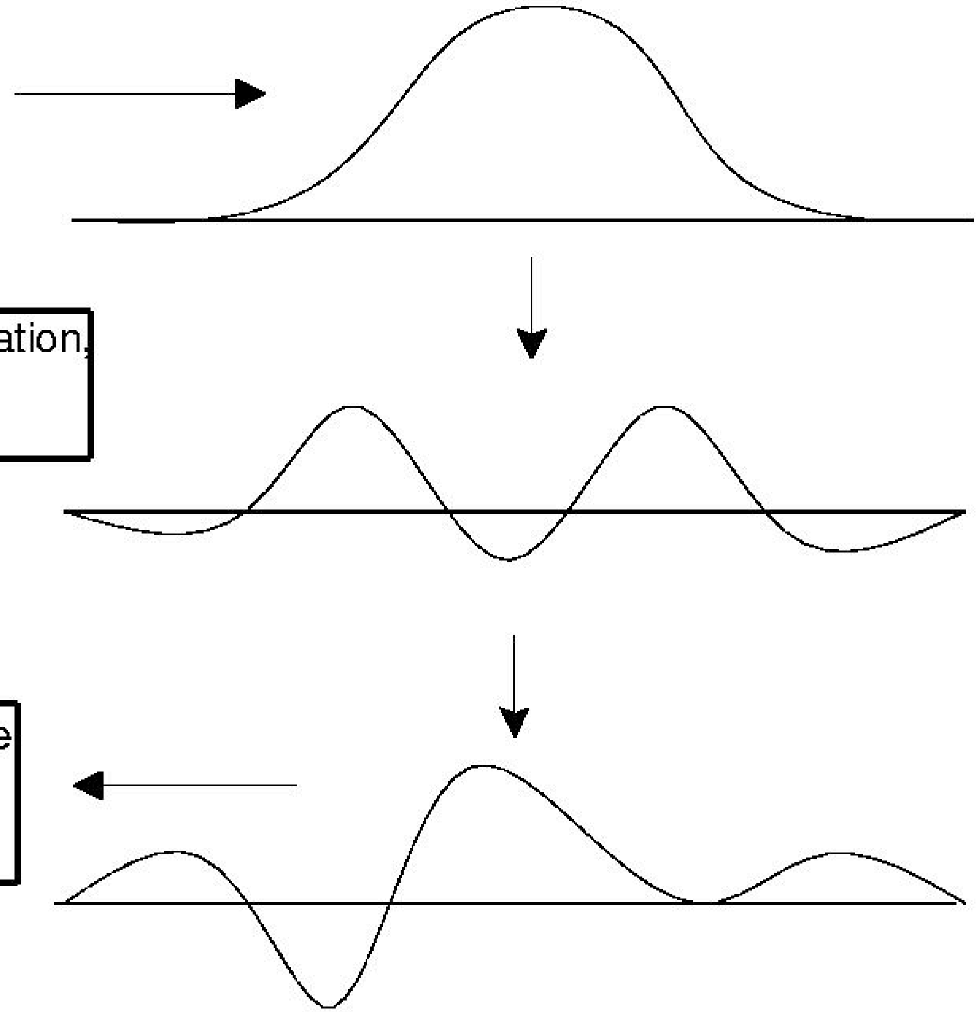
This is a nice example of Quantum Mechanics

Aside on Quantum Mechanics

Step 1: Write down the initial wavefunction of the particle using information about its position, momentum, etc.

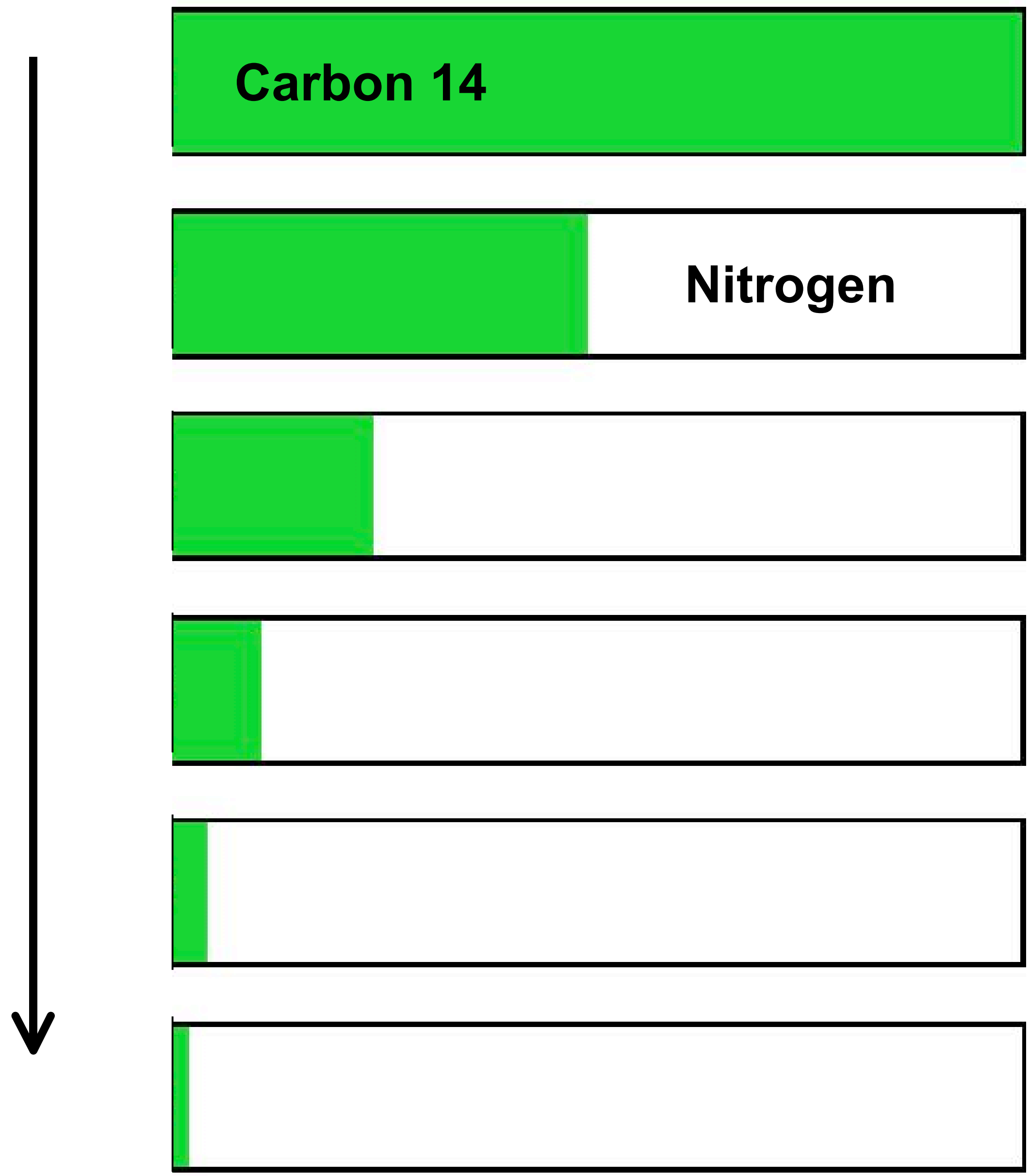
Step 2: Using Schrodinger's Equation, calculate how this wavefunction changes with time.

Step 3: At the desired time, use the wavefunction to calculate the probability the particle is found at any given position.

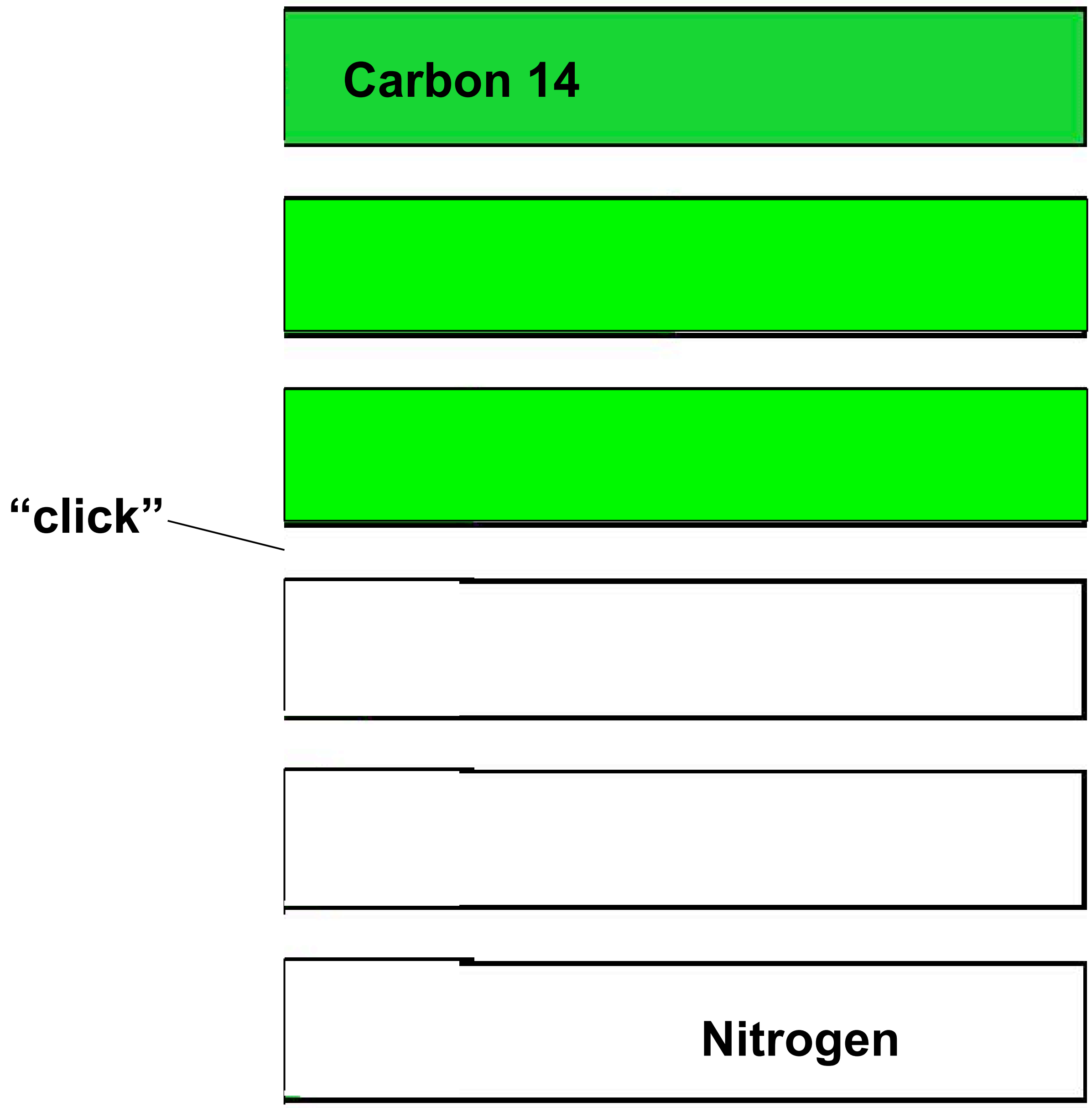


Similar Calculations accurately describe the probability that a Carbon-14 atom has decayed.

Similar Calculations accurately describe the probability that a Carbon-14 atom has decayed or not.



But what if you hang around



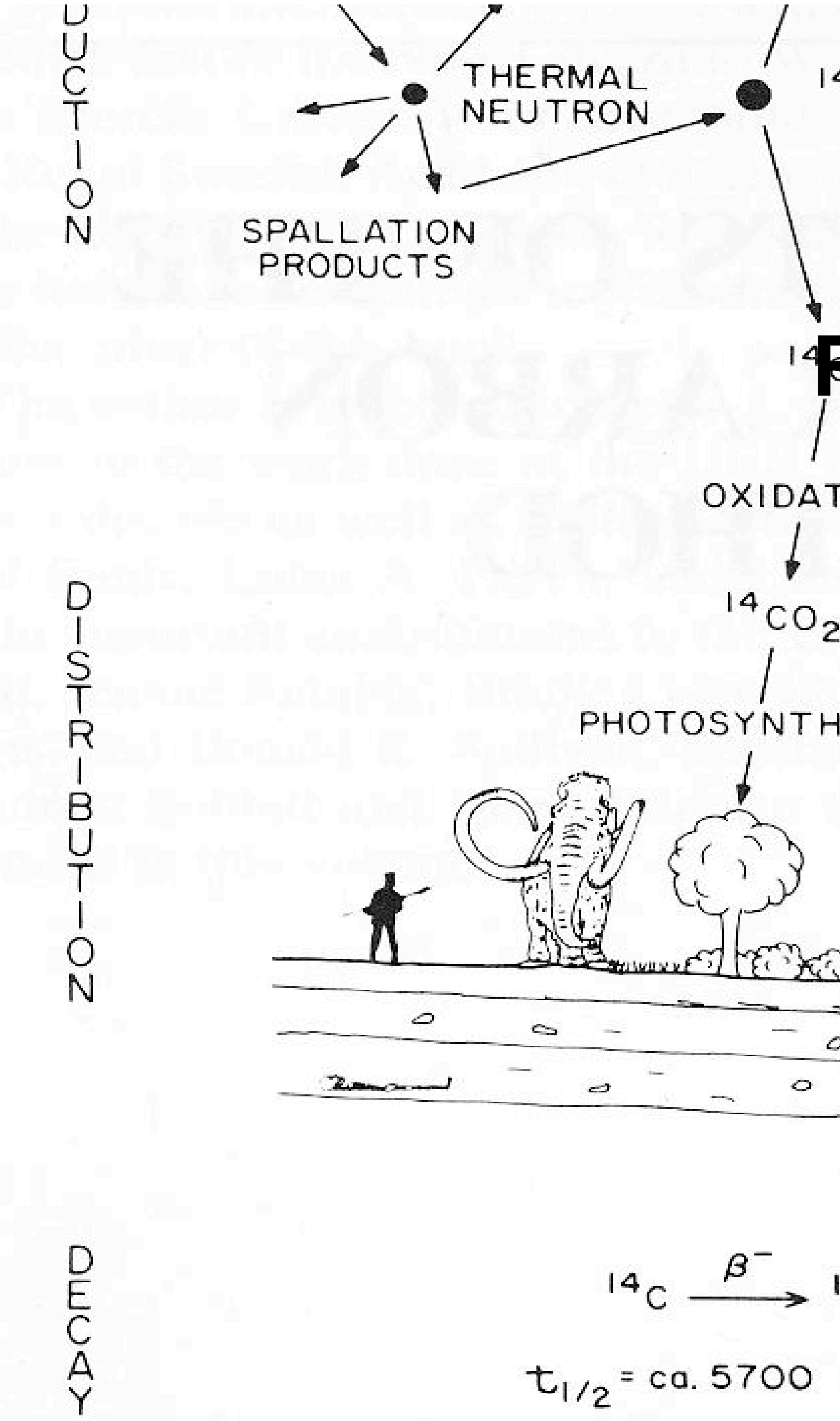
But, what happens when the probabilities become one particular answer

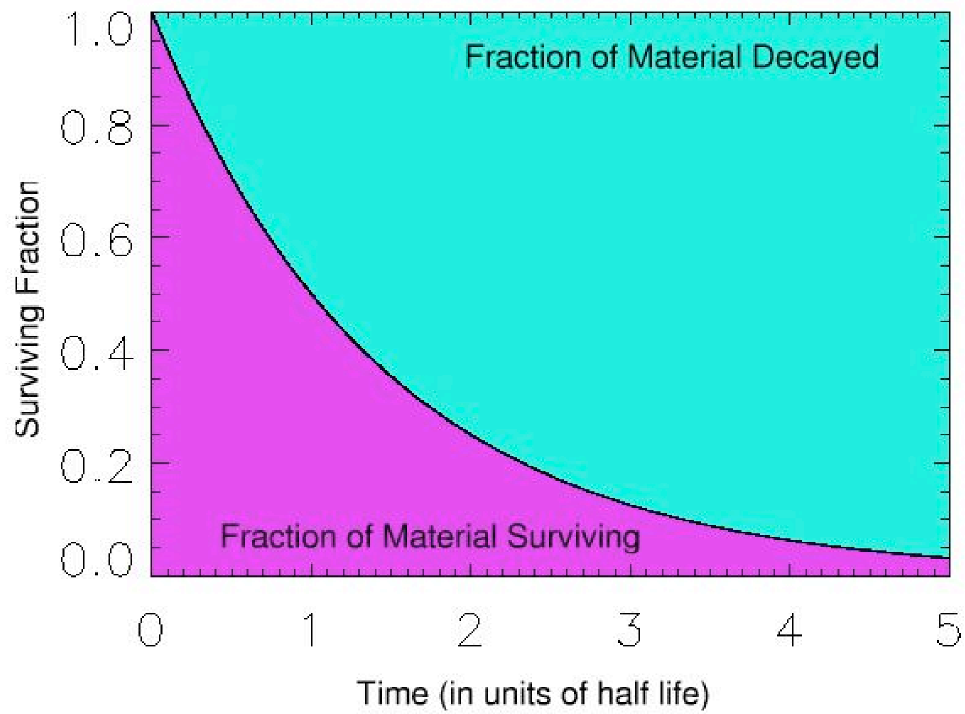
?

No one really knows….

Measuring Age with Carbon-14

$$R = \frac{\text{Current amount of Carbon-14}}{\text{Original amount of Carbon-14}}$$

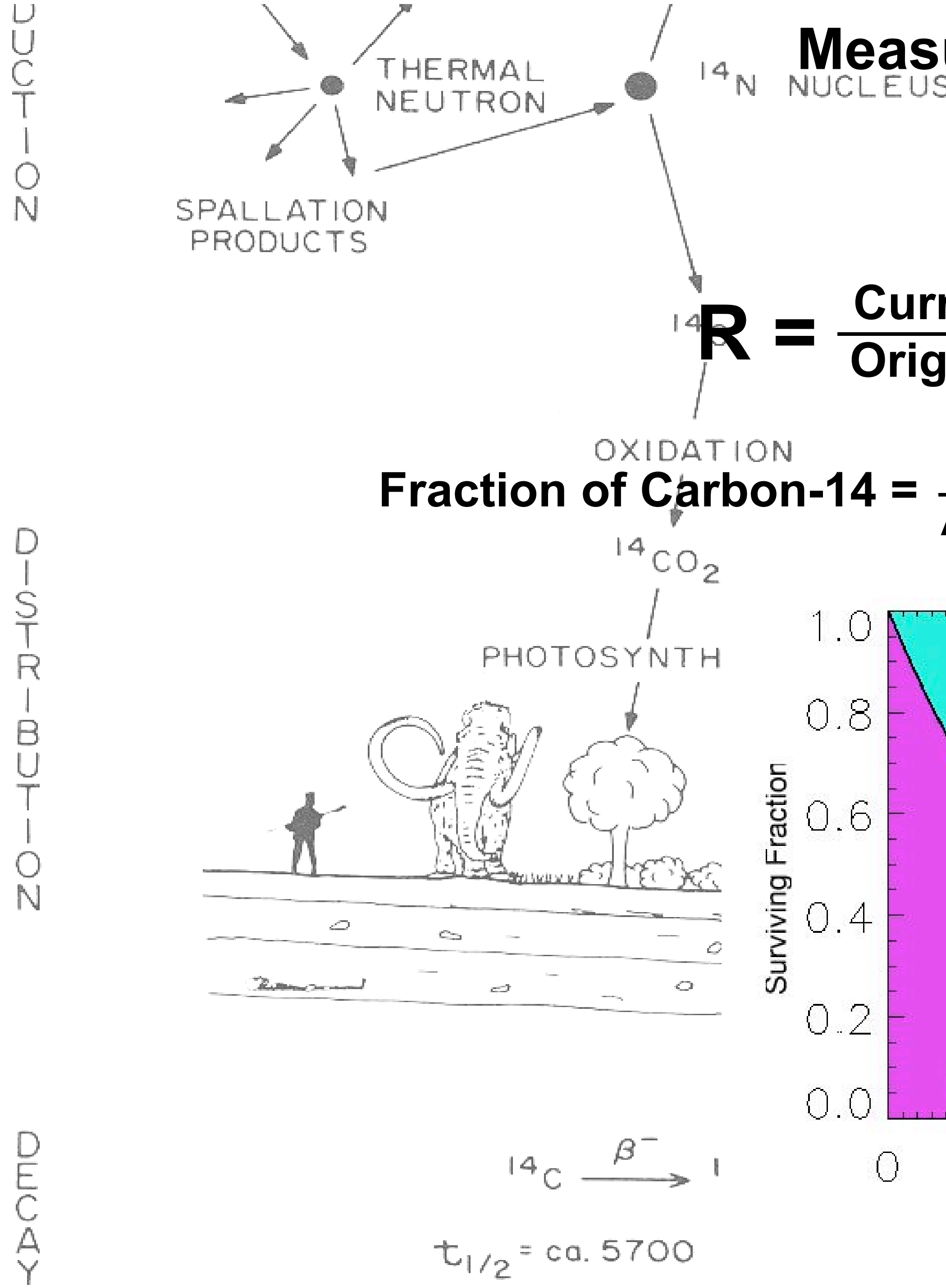


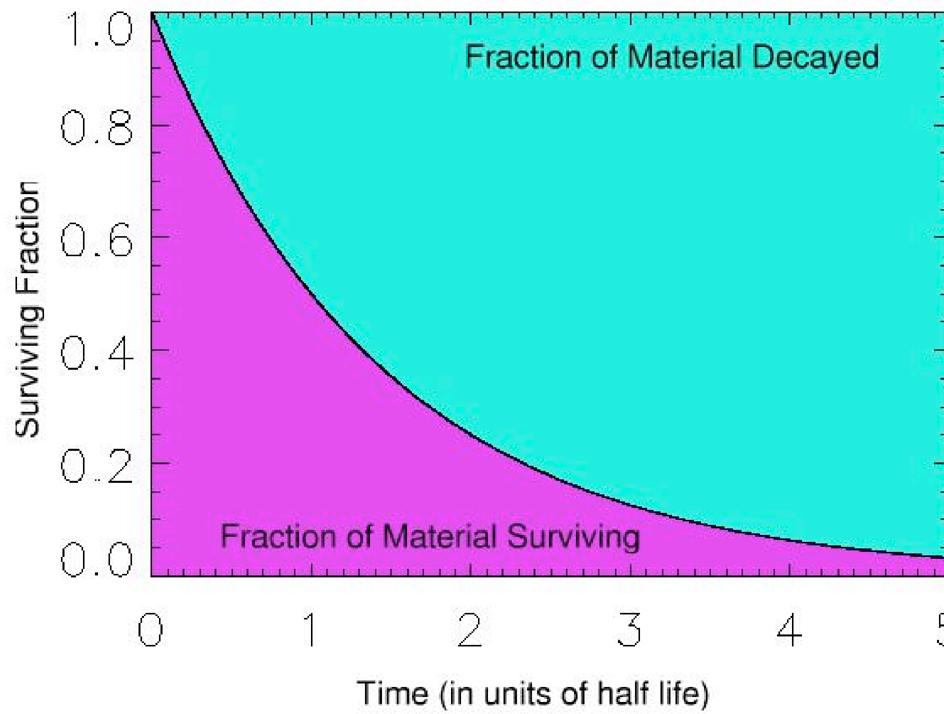


Measuring Age with Carbon-14

$$R = \frac{\text{Current fraction of Carbon-14}}{\text{Original fraction of Carbon-14}}$$

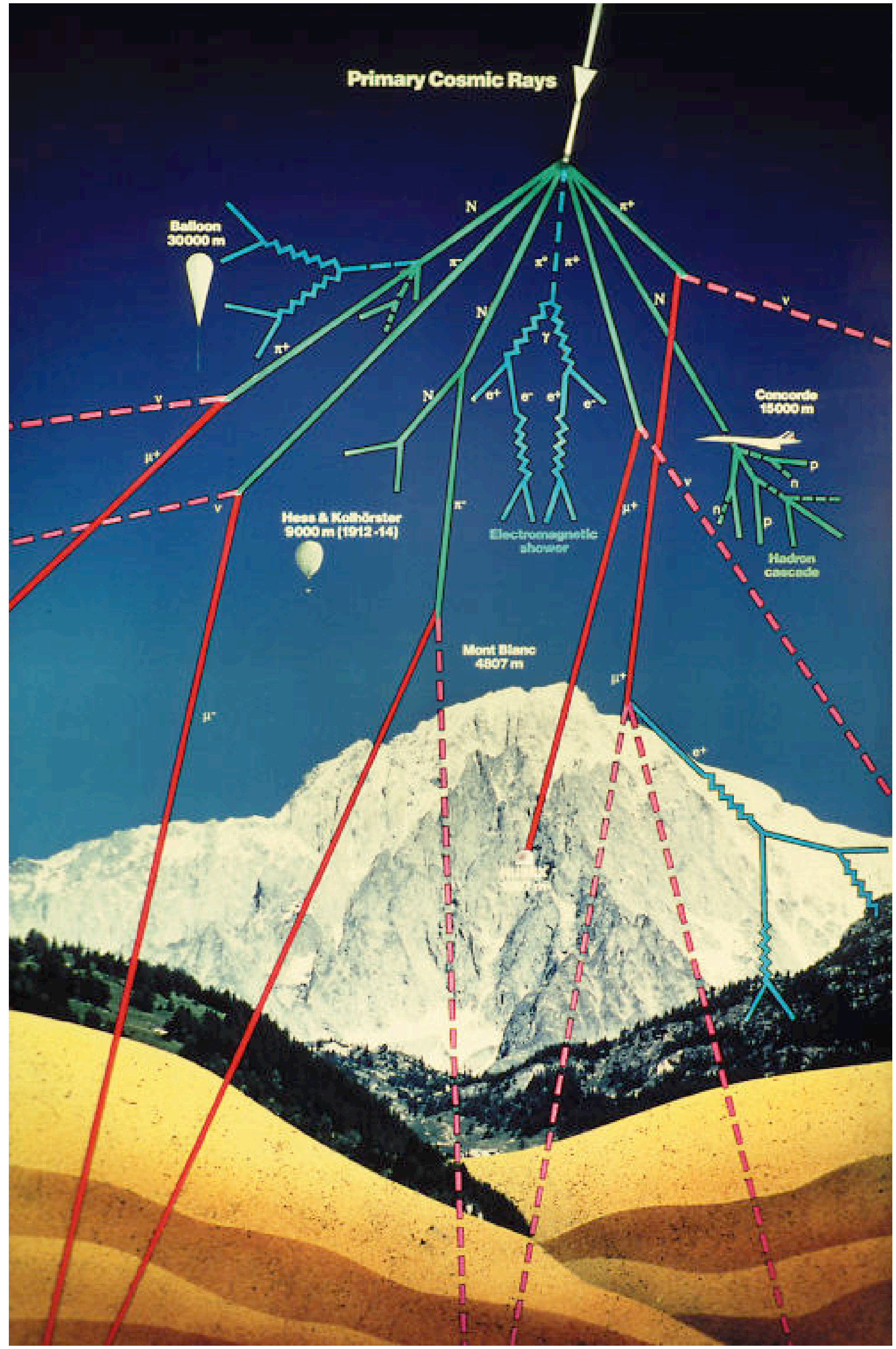
$$\text{Fraction of Carbon-14} = \frac{\text{Amount of Carbon 14}}{\text{Amount of all types of Carbon}}$$





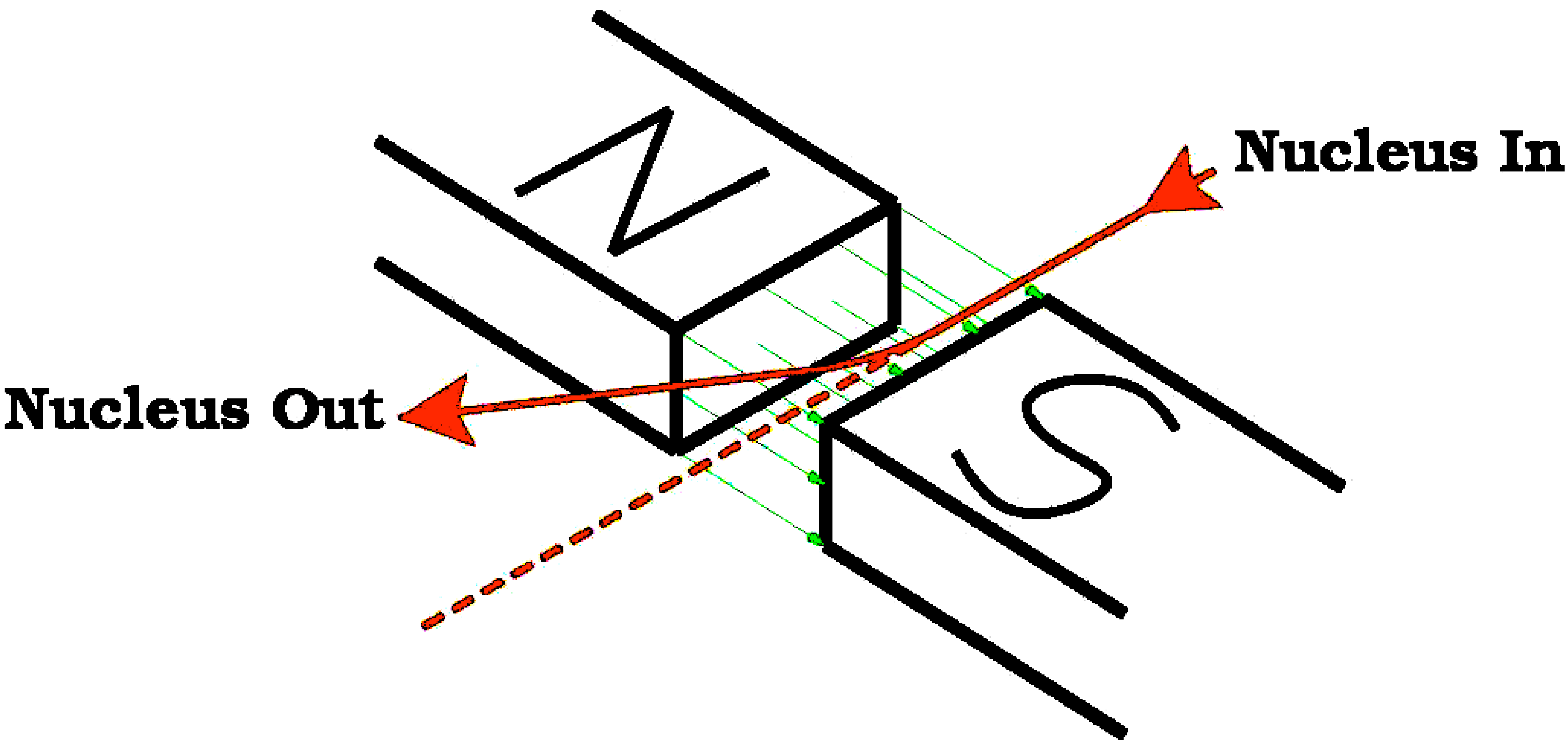
Carbon-14 is produced by cosmic rays

Cosmic rays are nuclei that move through space at speeds approaching the speed of light.

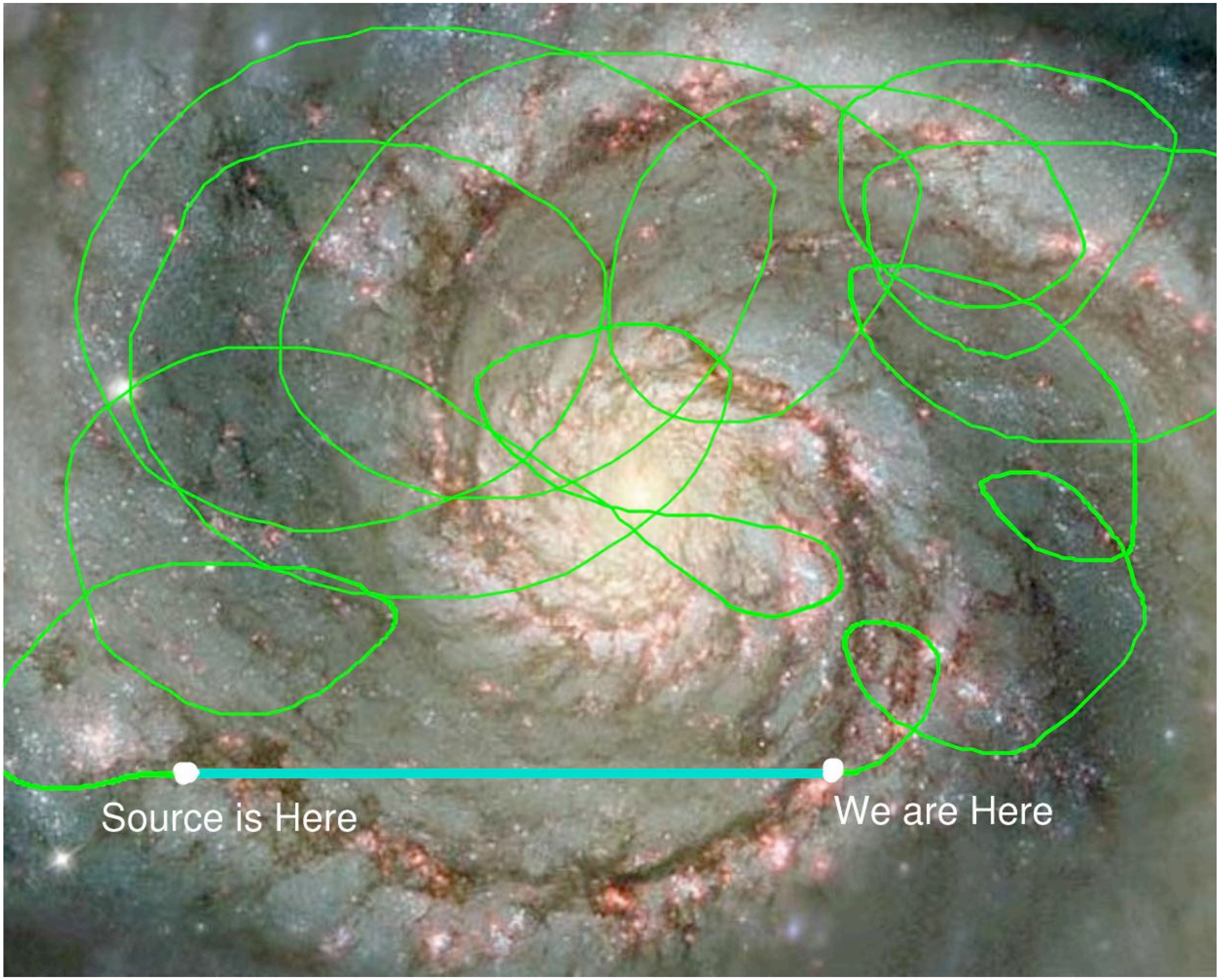


The Origin of Carbon-14: Cosmic Rays

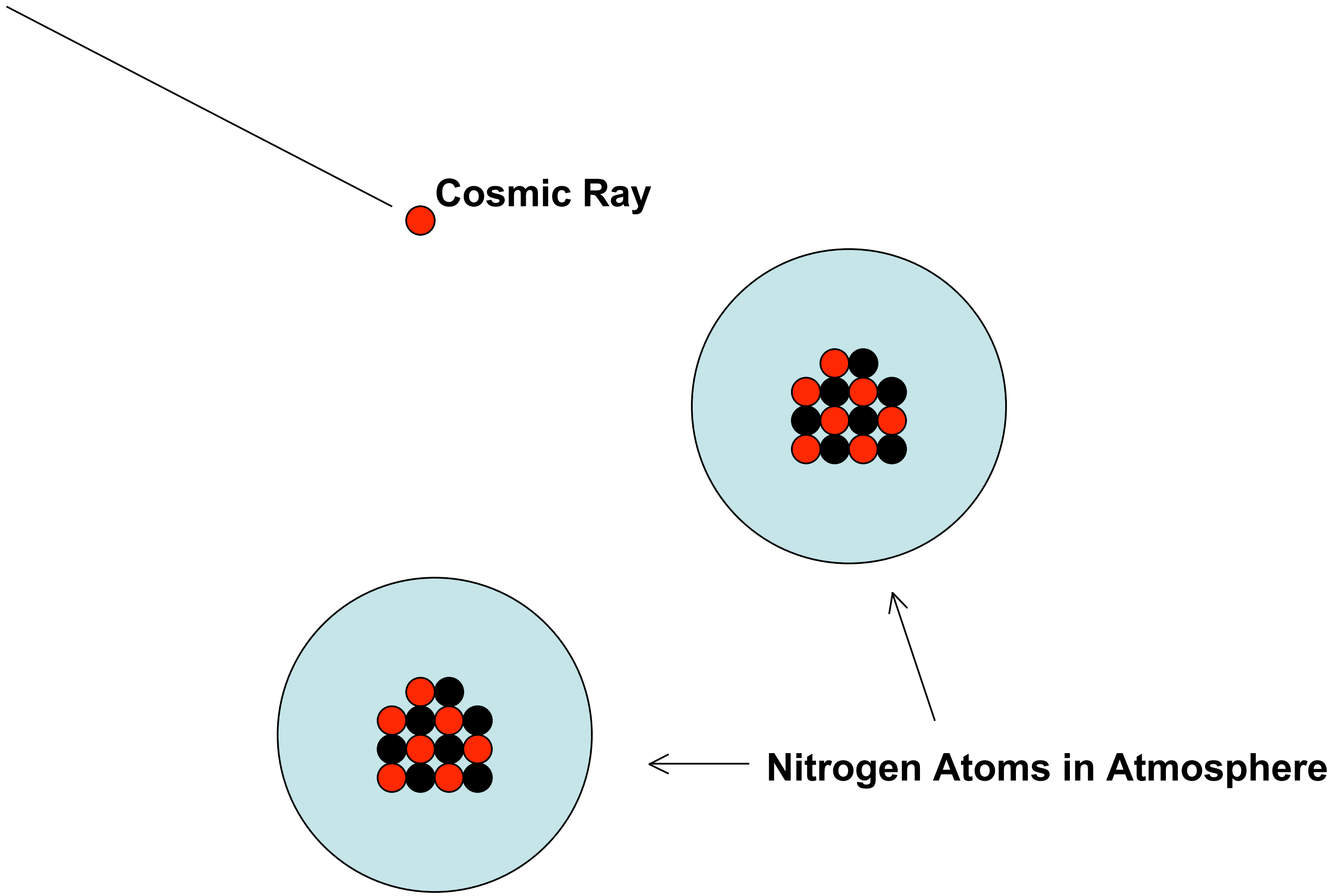
Their origin is uncertain because they are deflected by magnetic fields.



The paths of Cosmic Rays in the galaxy

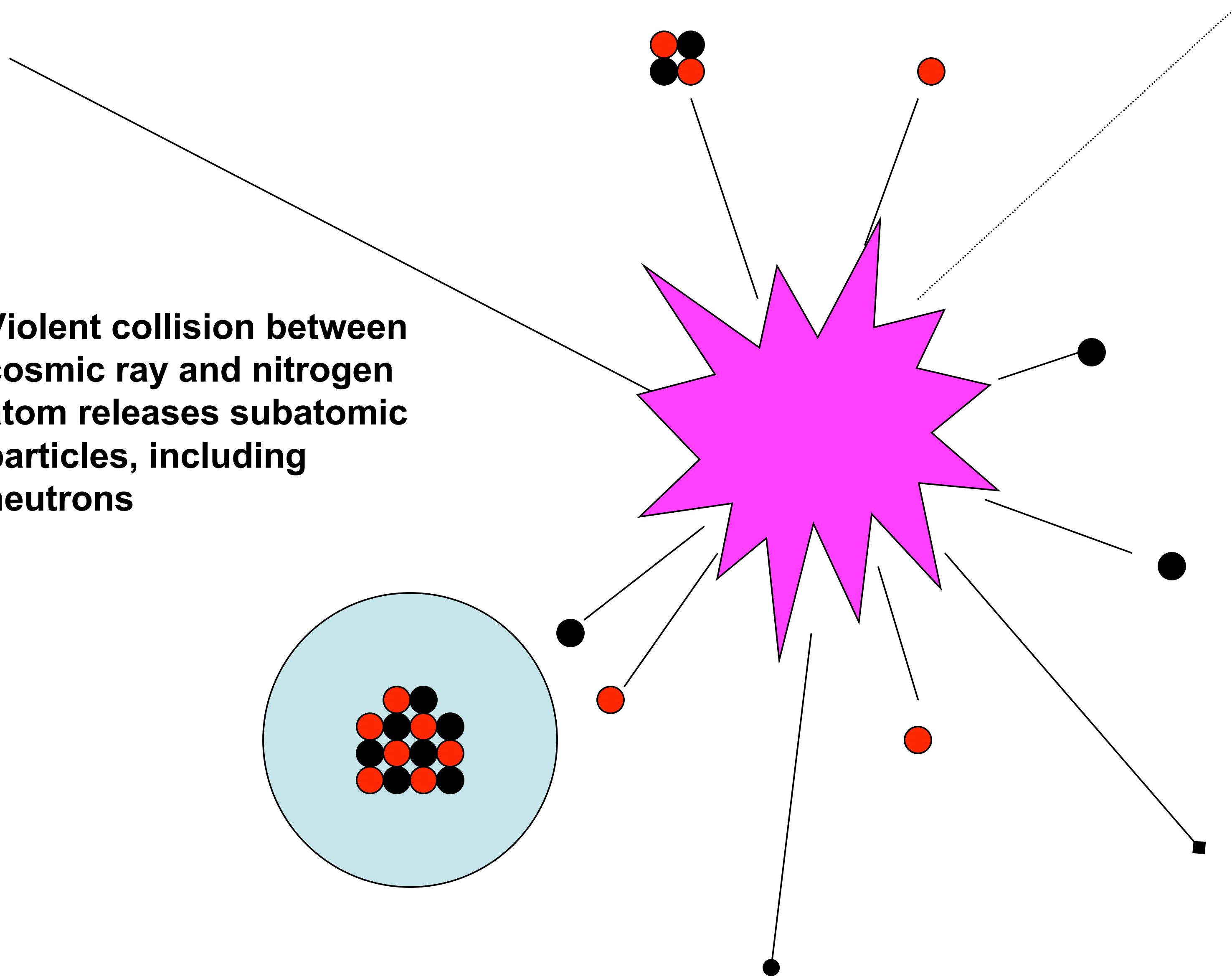


Cosmic Rays and Carbon-14



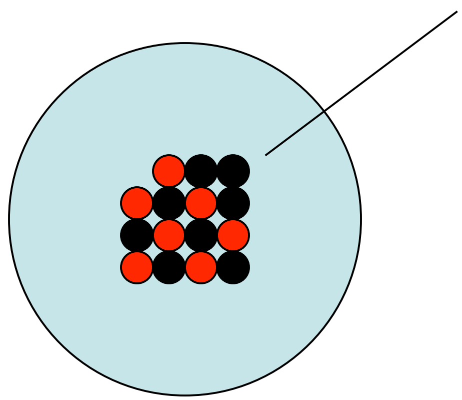
Cosmic Rays and Carbon-14

Violent collision between cosmic ray and nitrogen atom releases subatomic particles, including neutrons



Cosmic Rays and Carbon-14

These neutrons eventually are captured into another Nitrogen nucleus

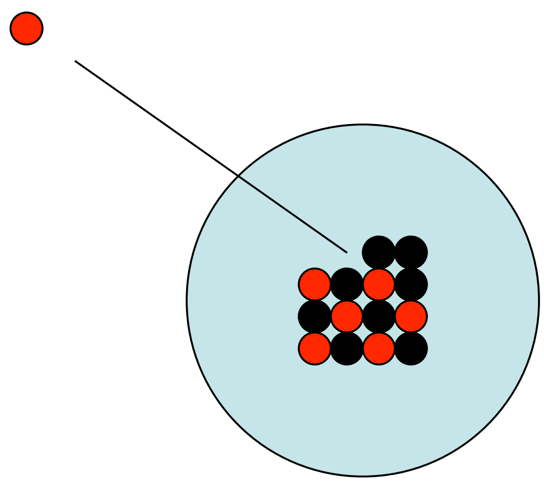


Cosmic Rays and Carbon-14

Currently, roughly 2 Carbon-14 atoms are produced every second per square centimeter at earth's surface

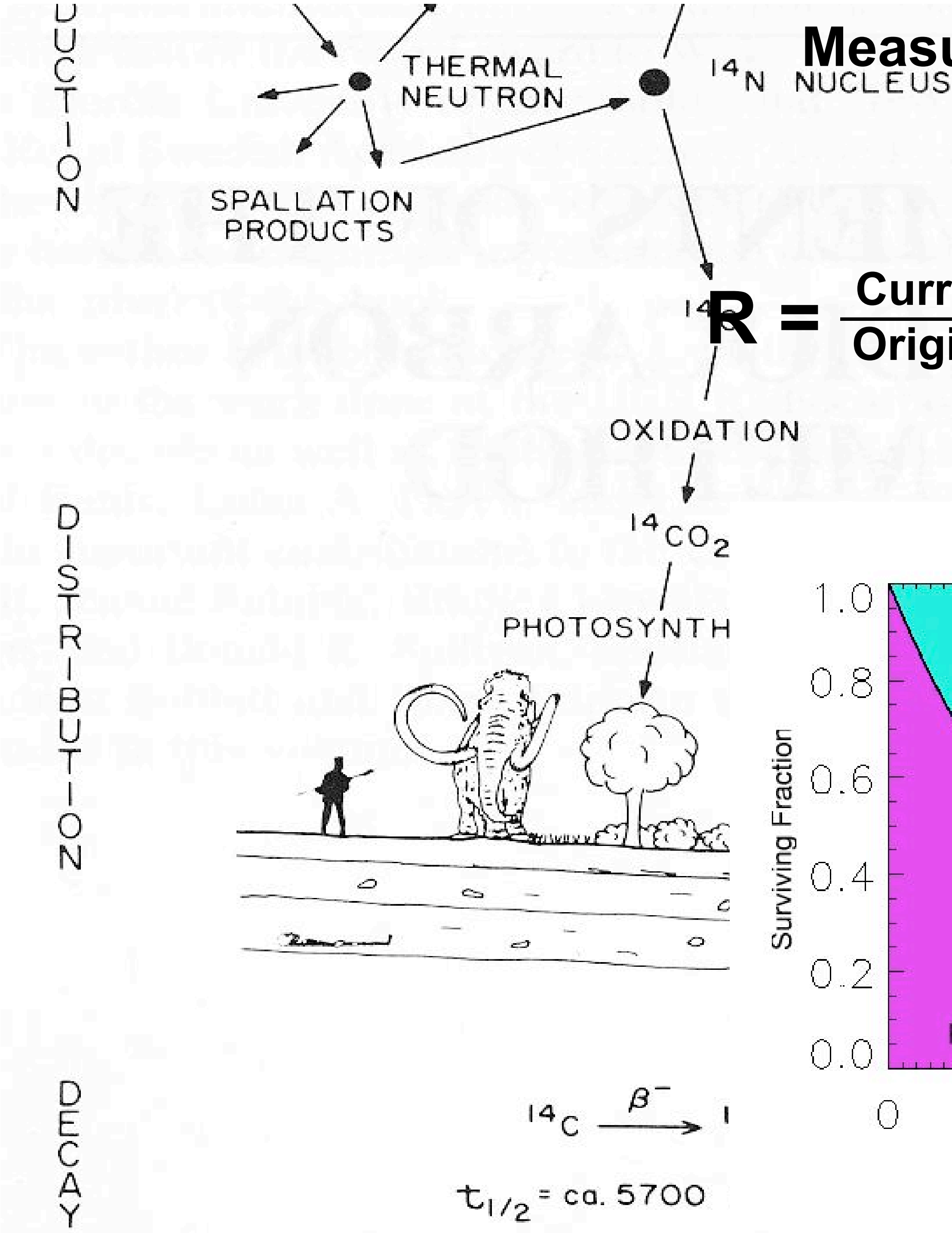
Only one in 1,000,000,000,000 carbon atoms is a Carbon-14 atoms

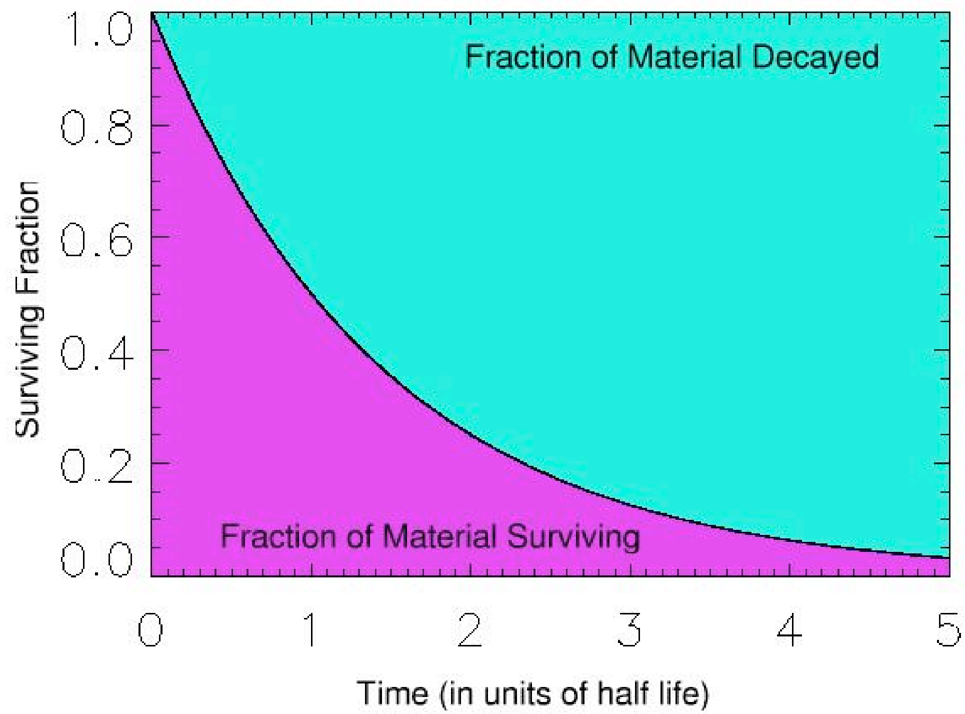
The nucleus then throws off a proton, leaving behind a Carbon-14 atom



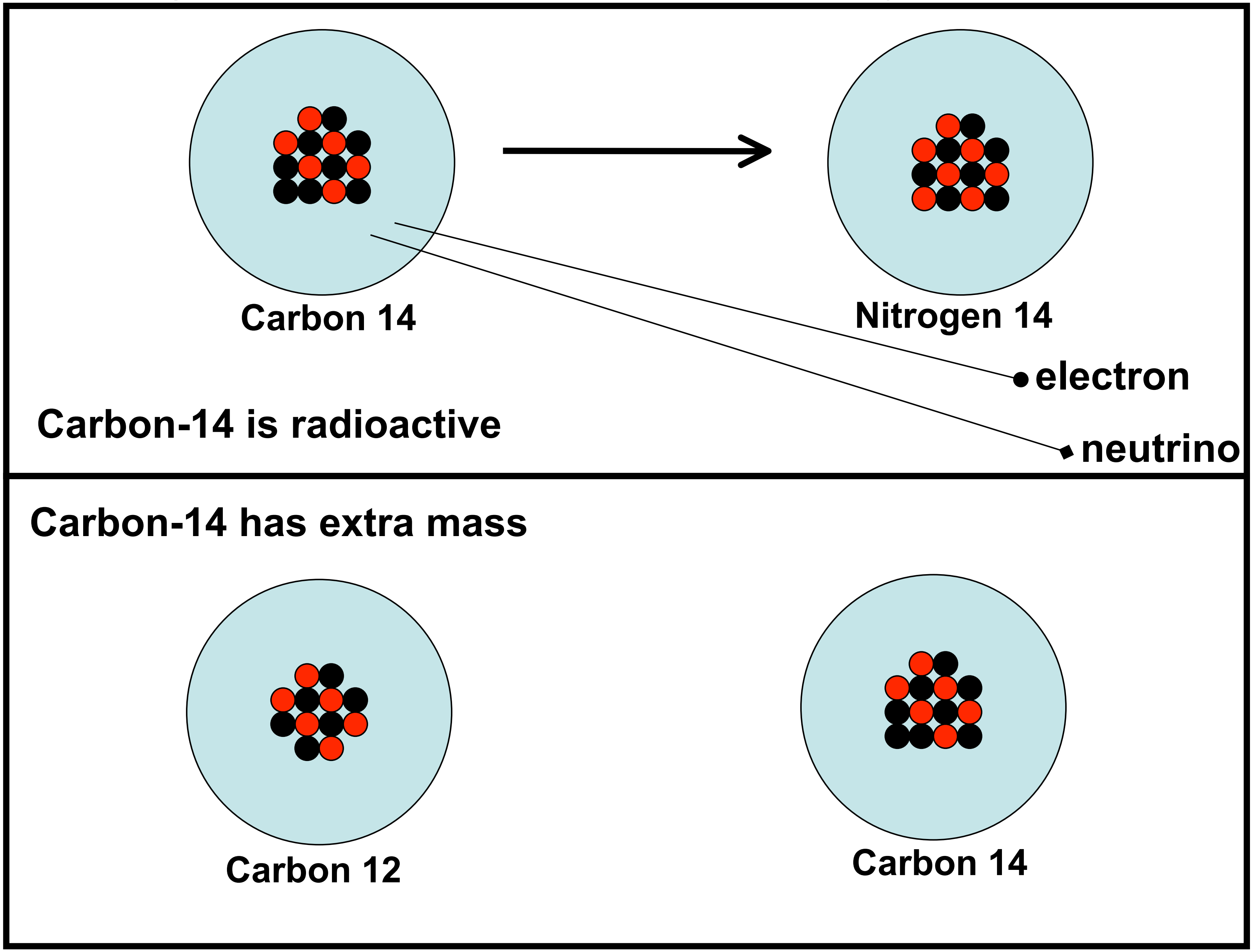
Measuring Age with Carbon-14

$$R = \frac{\text{Current fraction of Carbon-14}}{\text{Original fraction of Carbon-14}}$$

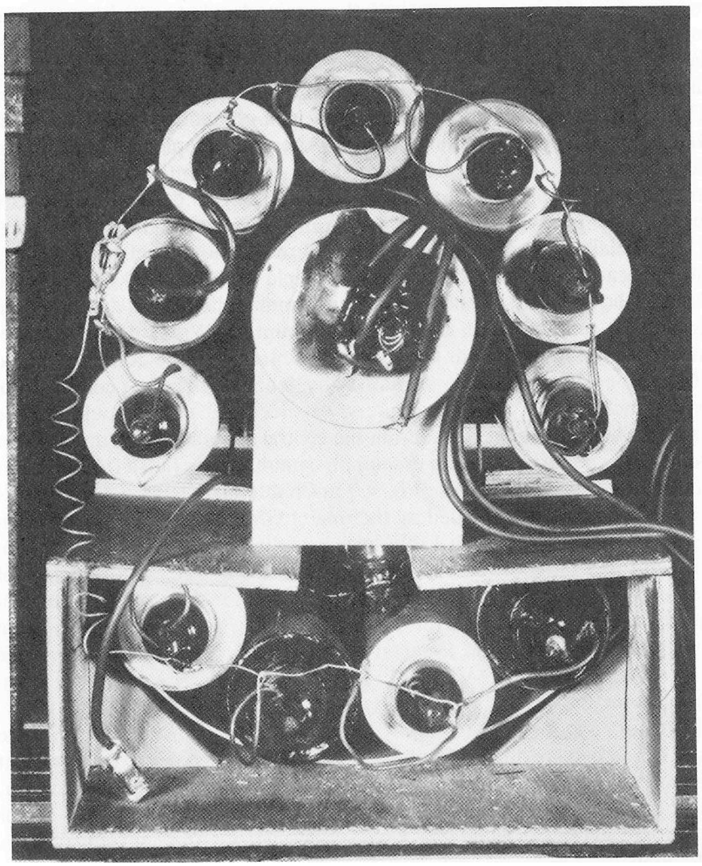




Measuring the current Carbon-14 fraction of objects

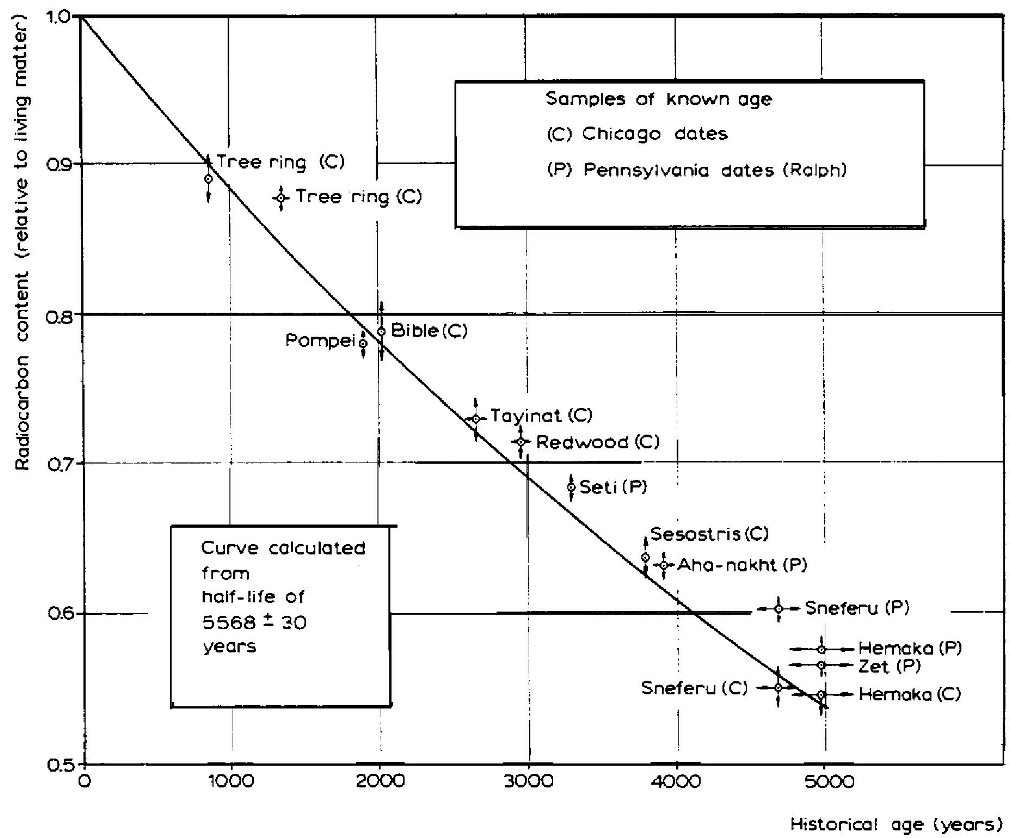


Measuring Carbon-14: Decay Methods

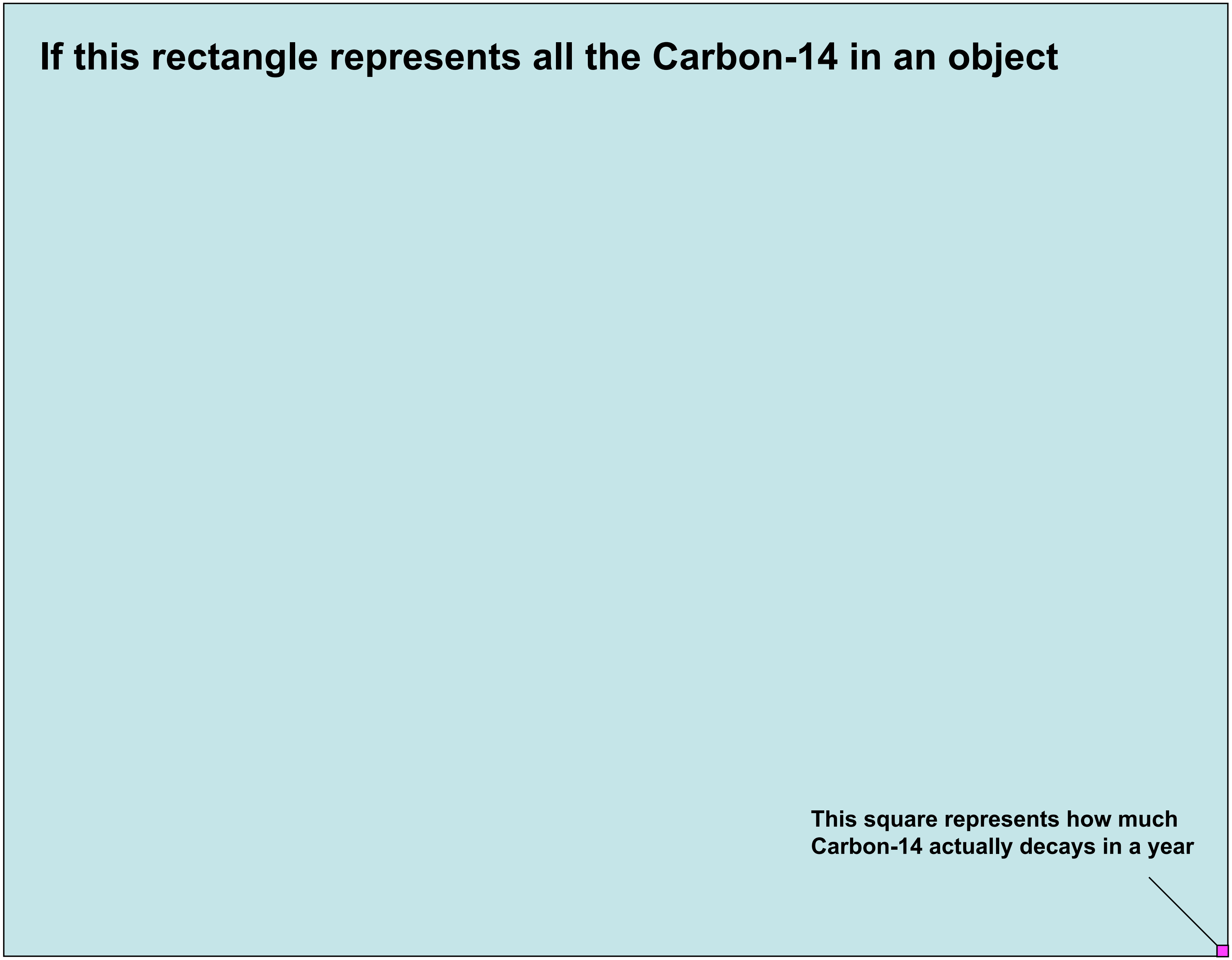


Libby's Measurement system

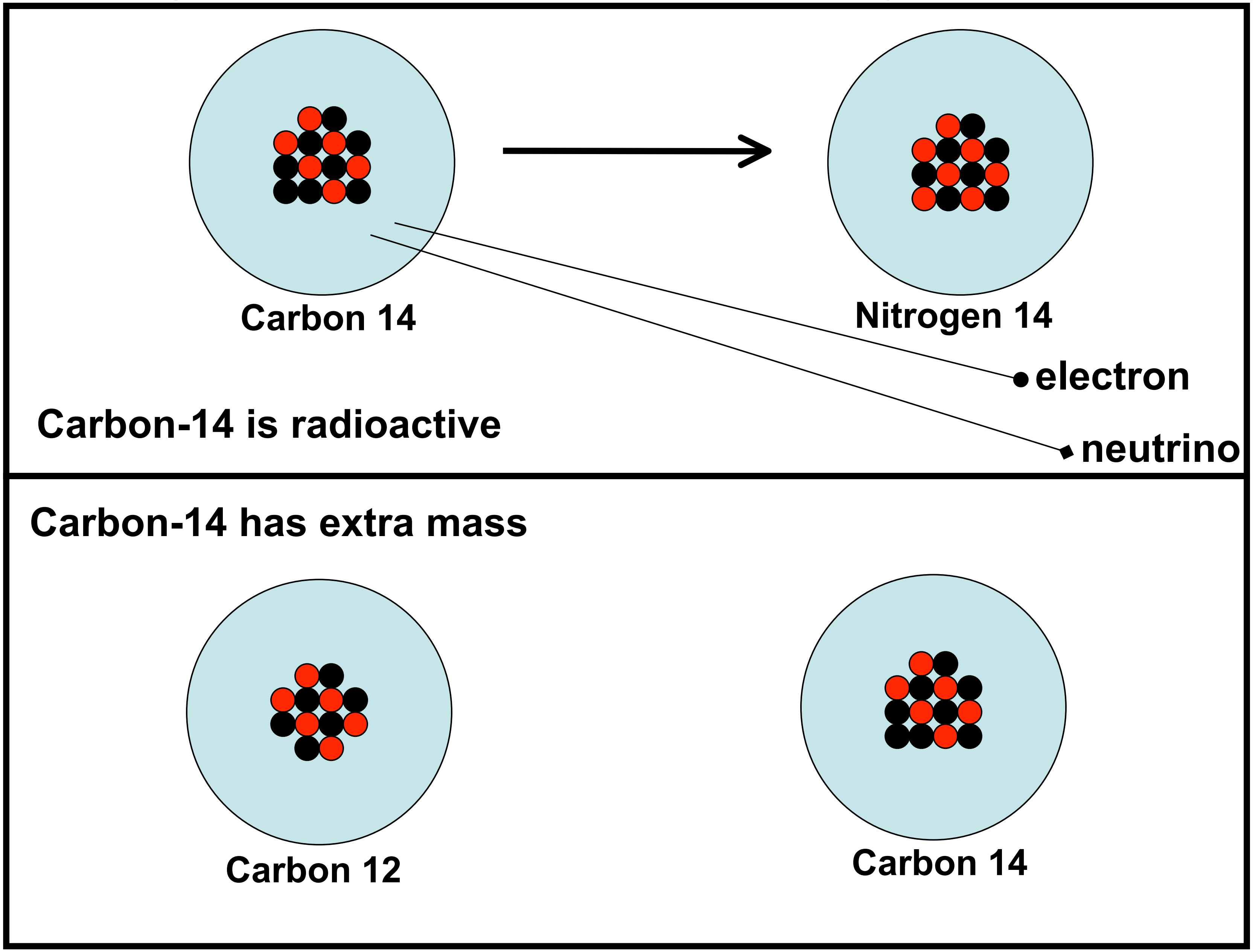
Libby's curve of knowns



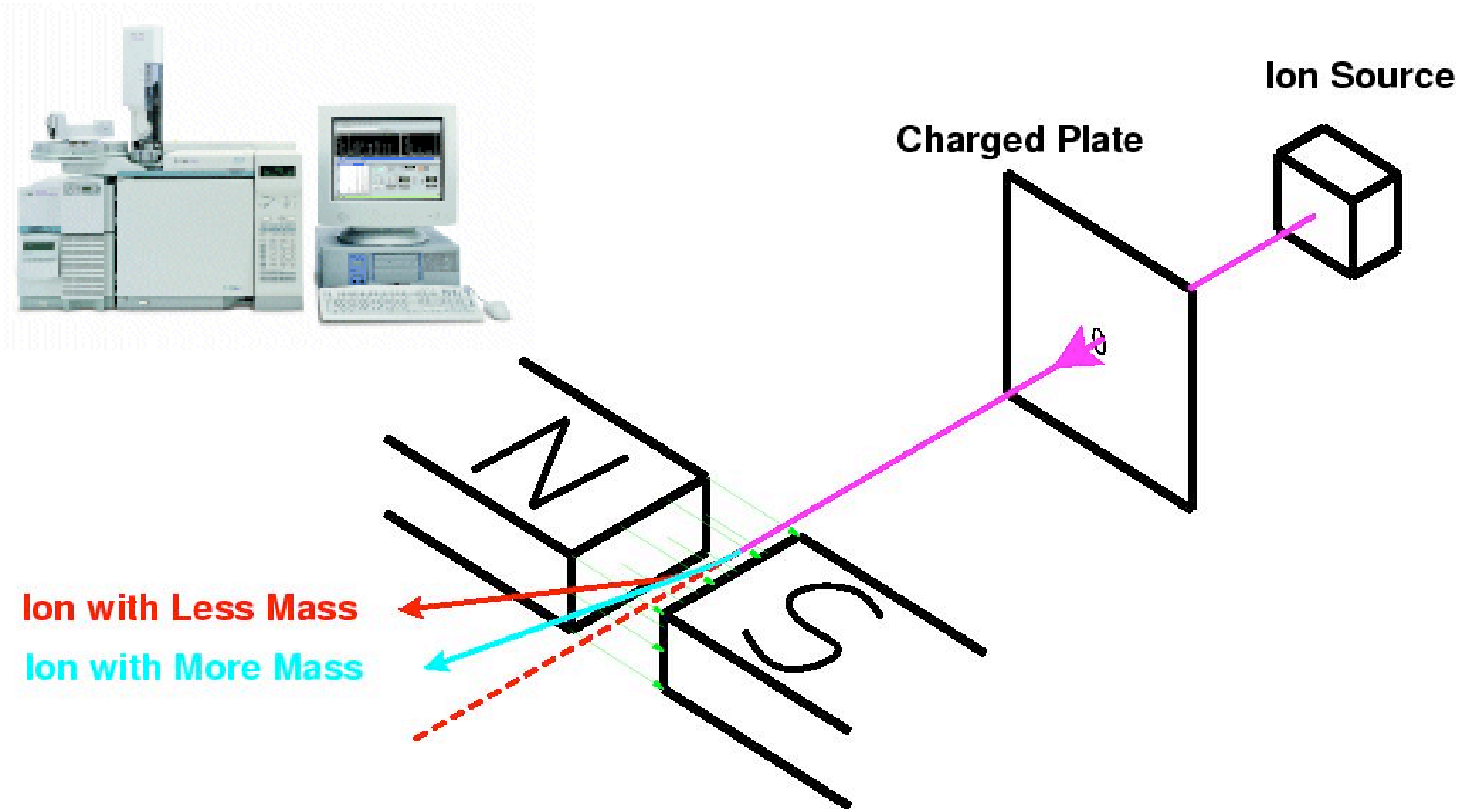
If this rectangle represents all the Carbon-14 in an object


If this rectangle represents all the Carbon-14 in an object
This square represents how much Carbon-14 actually decays in a year

Measuring the current Carbon-14 fraction of objects

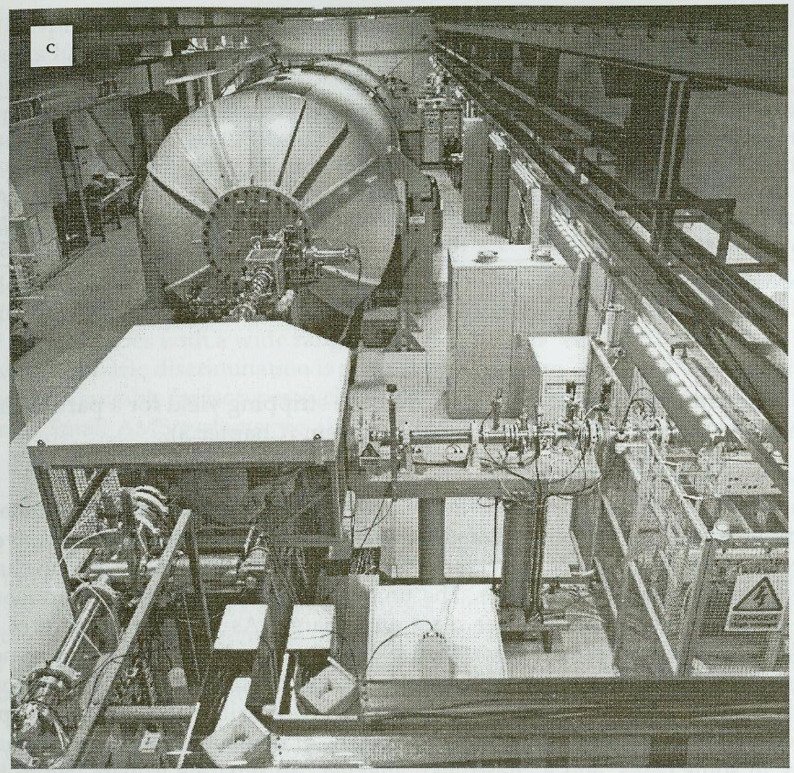


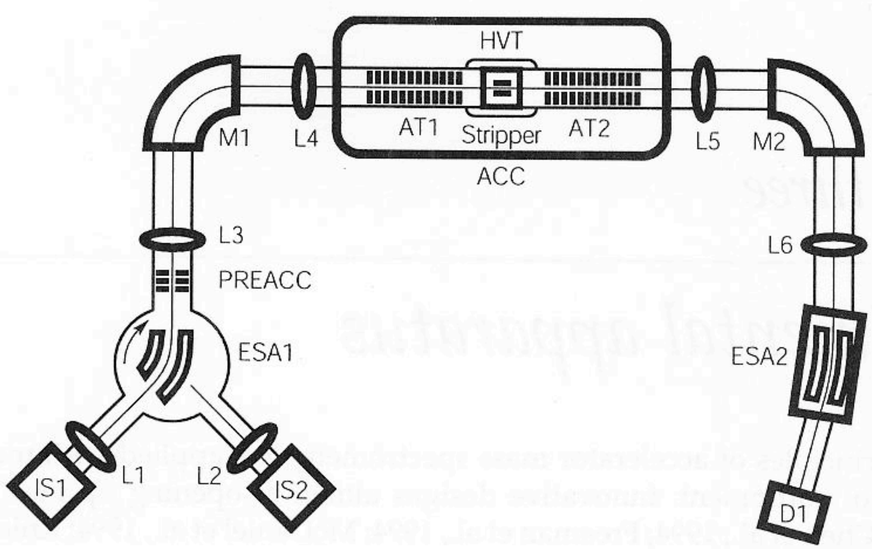
Measuring Carbon-14: Direct Counting with Mass Spectrometry

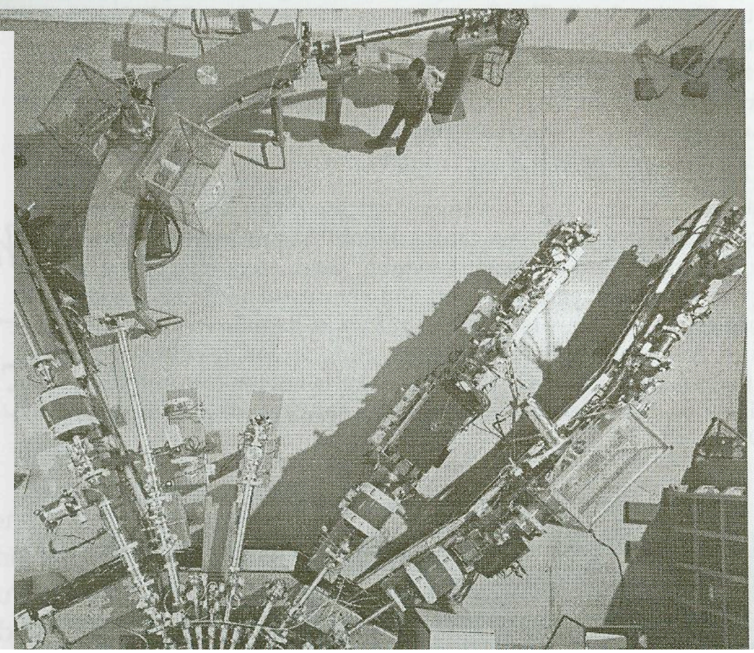


In order to measure the tiny Carbon-14 content of most objects, we need

Accelerator Mass Spectrometry







Next Time

Correcting and using Carbon-14