Results from Demo

- ^{241}Am (americium 241):

  α emitter

  Air, cardboard will stop it

- ^{90}Sr (strontium 90):

  β emitter

  Need lead sheet to stop it

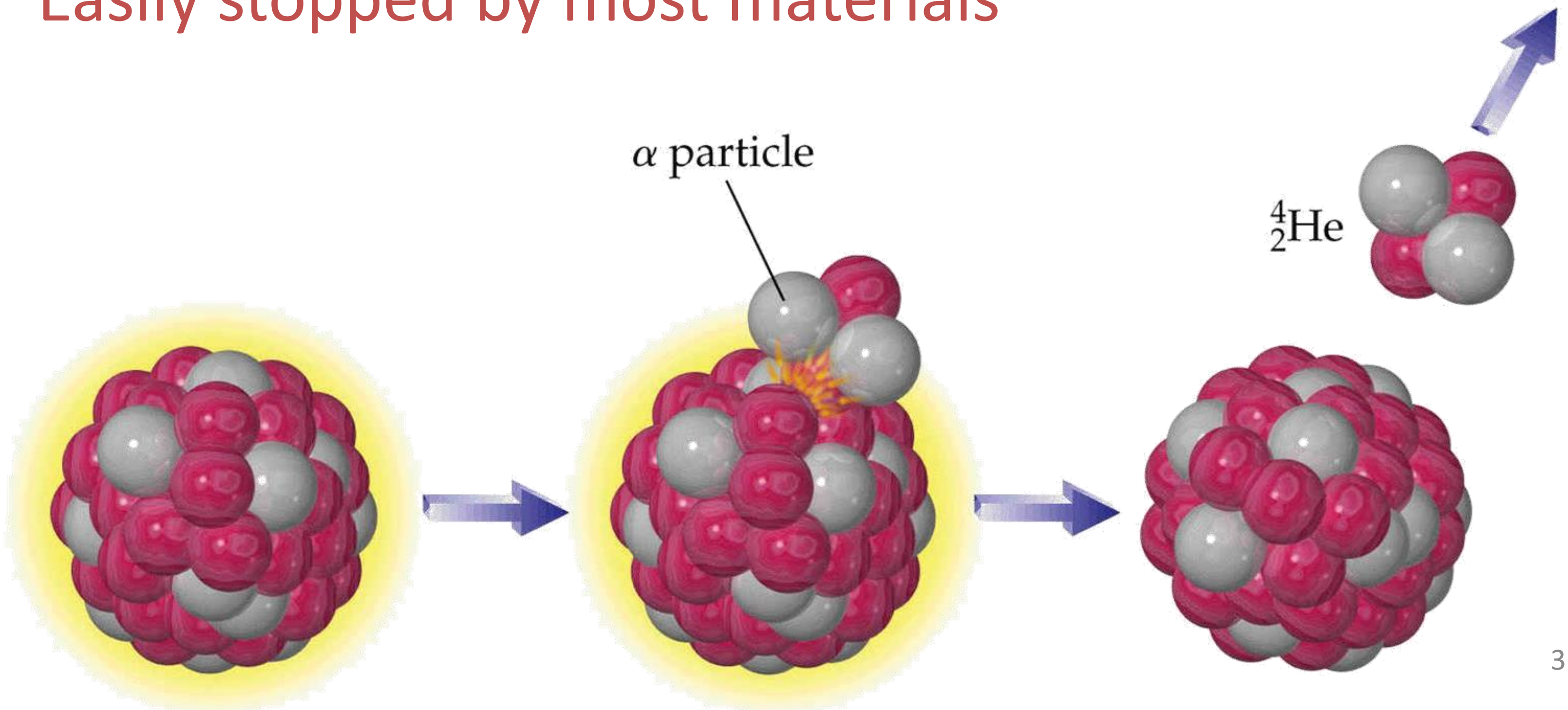
- ^{60}Co (cobalt 60):

  γ emitter

  Need several lead sheets to stop it

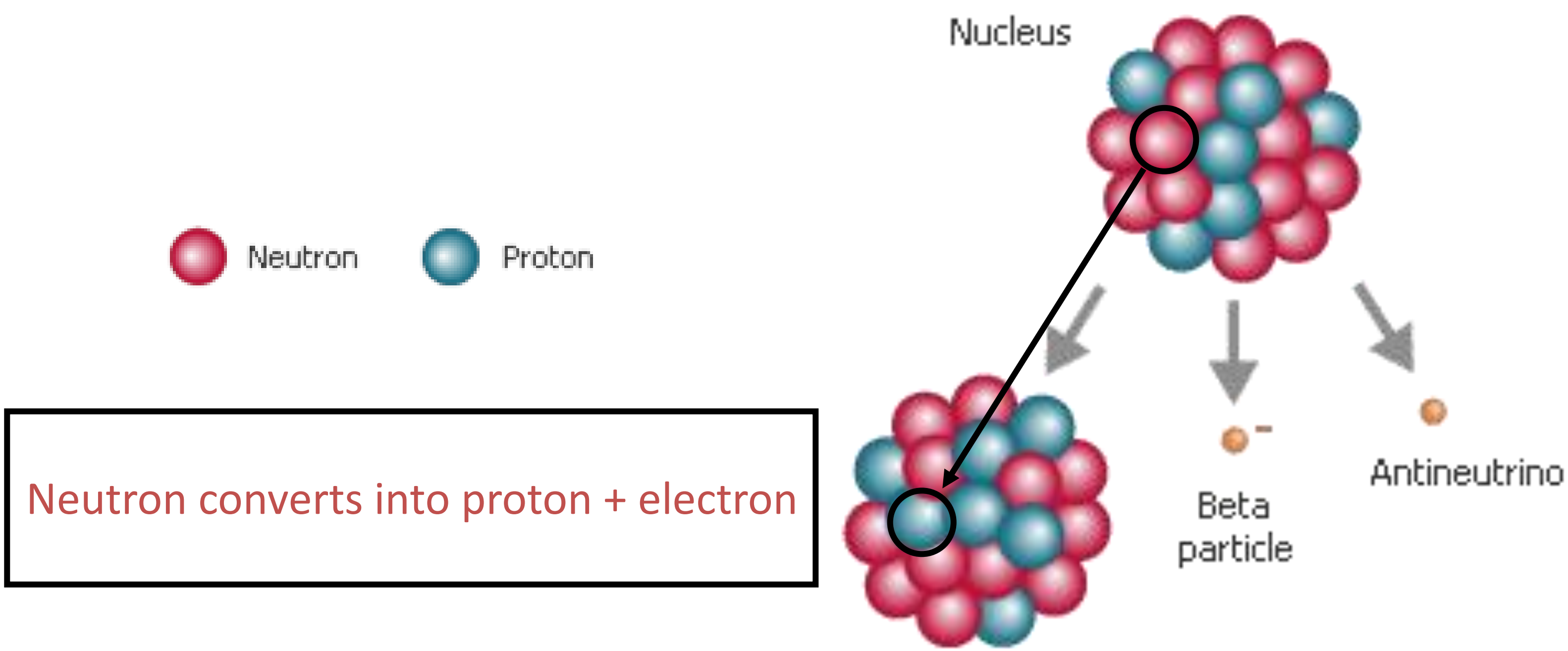
Alpha (α) radiation

- Particles !
- ^{4}He nuclei: 2 protons + 2 neutrons.
- Charge +2*e*
- Mostly emitted by heavy nuclei
- Easily stopped by most materials



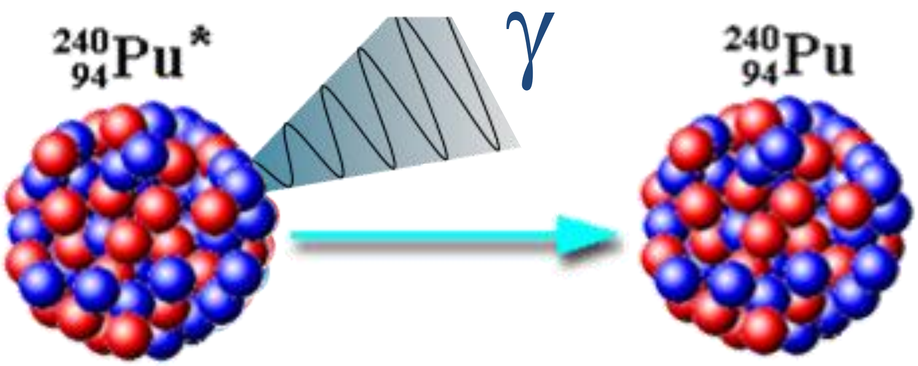
Beta (β) radiation

- Energetic electrons, charge –*e.*
- Emitted by light nuclei via *weak force.*
- Harder to stop than alpha particles.
- Neutron converts into proton + electron + “antineutrino”.
- Related process: proton converts into neutron + “positron” + neutrino.

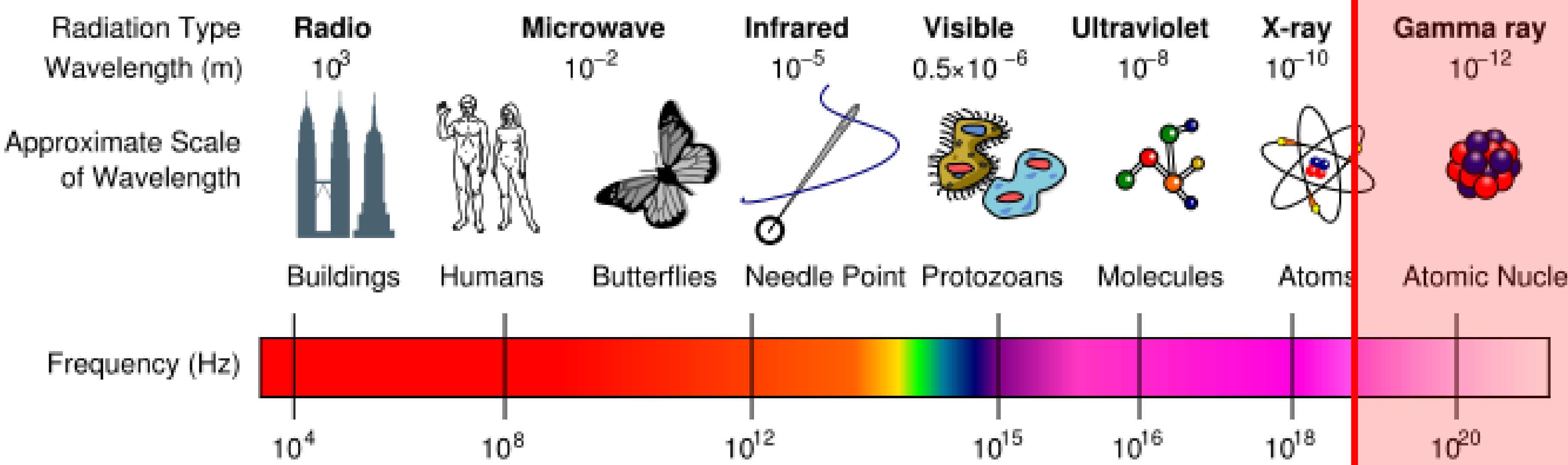


Gamma (γ) radiation

- Electromagnetic waves !
- Highest energy (highest frequency, shortest wavelength) of EM spectrum
- Emitted by excited nuclei
- Hardest to stop



Photon energy



Photon energy

$\Delta E = h\,f$

is enough energy to:

Excite molecular vibrations

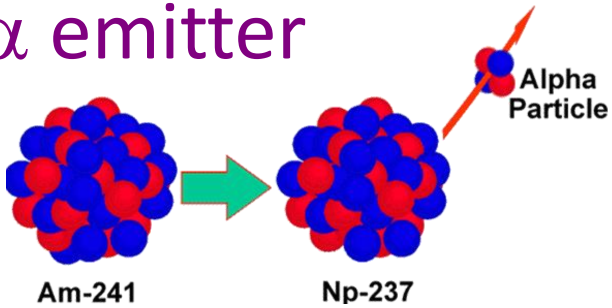
Excite atoms

Break chemical bonds

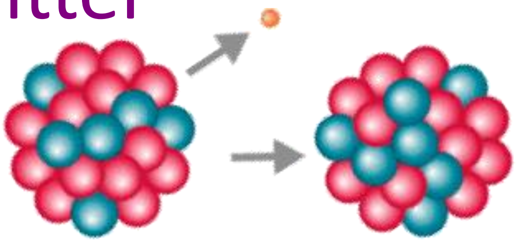
Excite nuclei

Demo materials

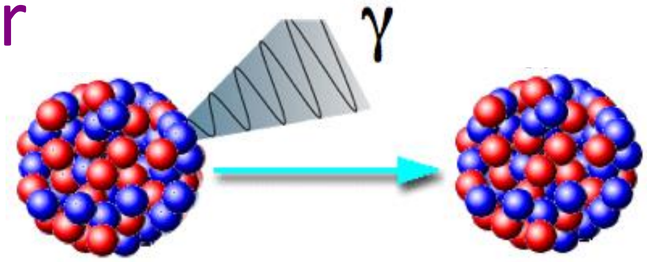
- ^{241}Am (americium 241): α emitter



- ^{90}Sr (strontium 90): β emitter

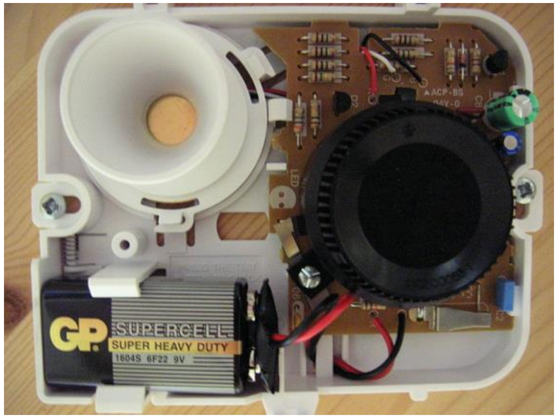


- ^{60}Co (cobalt 60): γ emitter



Smoke Detectors

- There are two types: Ionization and Photoelectric.
- Photoelectric smoke detectors work by detecting light scattered by the smoke. Best when there is visible smoke (large smoke particles).
- Ionization smoke detectors work even when there is little visible smoke (smaller particles). A small radioactive source (0.3 micrograms of americium-241) keeps ionizing the air. The resulting current is monitored. In the case of fire, smoke particles absorb some of the ions, reducing the current, which triggers the alarm.



Inside a basic ionization smoke detector. The black, round structure at the right is the ionization chamber. The white, round structure at the upper left is the piezoelectric buzzer that produces the alarm sound.

Clicker

A radioactive source is observed to emit radiation that is blocked by lead foil but not cardboard. The emitted radiation most likely consists of

A. Alpha radiation

B. Beta radiation

C. Gamma radiation

D. No way to tell

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Radioactivity Health Effects

Radioactive decays typically produce decay products of α's, β's, γ's, and neutrons (from various nuclear reactions), all of which can have biological effects.

The basic problem is that when these energetic particles pass through matter, they can ionize matter, knocking out atomic electrons, breaking molecules, damaging DNA, and killing cells, if there is enough radiation.

The basic strategies for dealing with this are:

- source reduction: avoid generating radioactive material
- time: minimize time of exposure to radioactive material
- distance: keep as far away as you can
- shielding: keep material that absorbs radiation between you and radiation sources

Health risks of radiation exposure

- Units are confusing:
  - rads, rems, sieverts (Sv)
- We will use Sv and mSv (= 10^{-3} Sv)
- It is essentially a unit of bio-damage
- We all get about 2-3 mSv every year from natural sources
- 1 Sv (at once) will make you sick
- 5 Sv (at once) will probably kill you

Radiation Doses

Ionizing radiation doses are measured in Grays or Sieverts.

Gray refers to the amount of energy absorbed per kg of tissue:

$$1 \text{ Gray} = 1 \text{ Gy} = 1 \text{ J/kg}$$

Because different types of radiation have different biological effects for the same energy deposited, there is another unit that takes this "quality factor" into account:

γ: 1 Sievert (Sv) = 1 Gy

β: (1.0-1.5) Sv / 1 Gy

n: (3-5) Sv / 1 Gy

p: 10 Sv / 1 Gy

α: 20 Sv / 1 Gy

Radiation Exposure

Typical annual radiation dose is ≈ 2-3 mSv/year.

Radiation workers are allowed up to 50 mSv/year.

A one-time exposure of about 5 Sv kills about 50% of people.

Smaller exposures cause cataracts, kill skin, increase cancer risks, etc.

For smaller "chronic" doses, the effects of radiation are much more poorly known. The typical standard is the "linear no-threshold" model: The number of cancers in a population is most likely directly proportional to the radiation exposure.

Sadly, much of the information comes from Hiroshima & Nagasaki nuclear attacks, nuclear shipyard workers, and the Chernobyl and Fukushima nuclear accidents.

Health risks of radiation exposure

<u>Three different kinds of damage</u>:

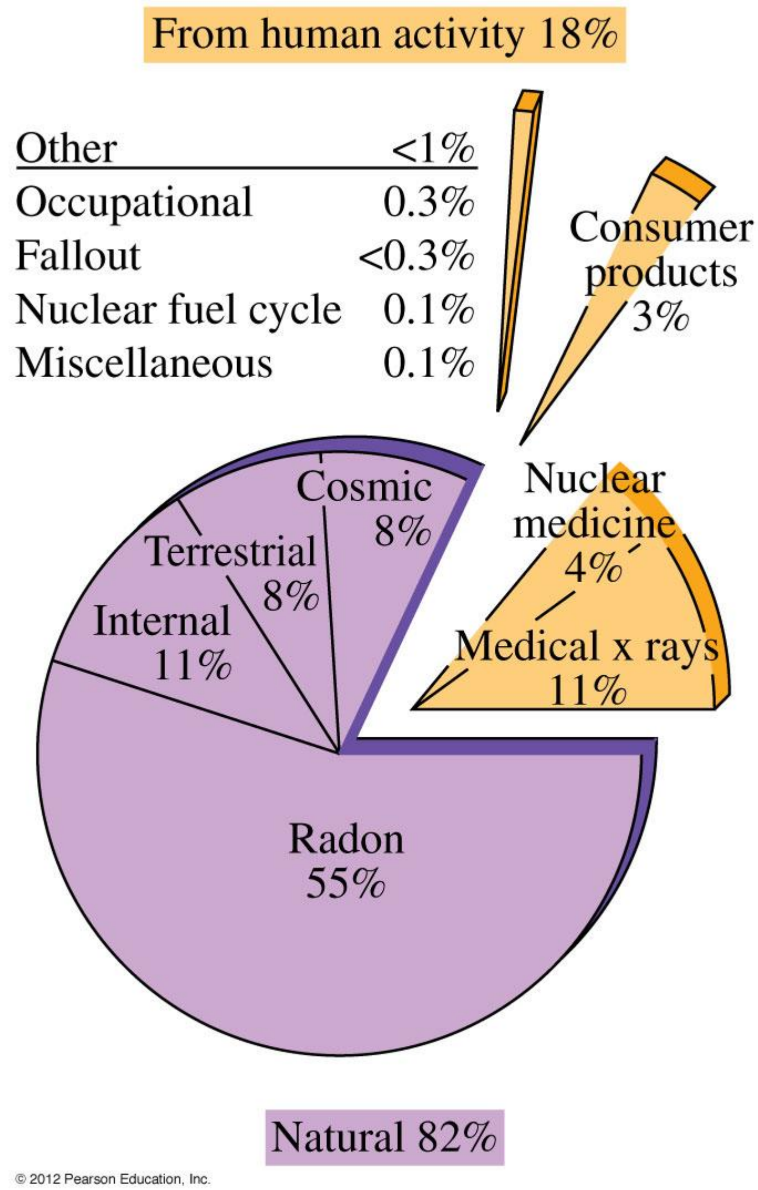
- Radiation sickness (sudden exposure)
  - Mostly damage to bone marrow and intestinal lining
  - 1 Sv will make you sick
  - 5 Sv will probably kill you
- Mutations (lifetime cumulative exposure)
  - Affects your children, not you
- Cancer (lifetime cumulative exposure)

Biggest concern

Acute vs. Chronic Dose

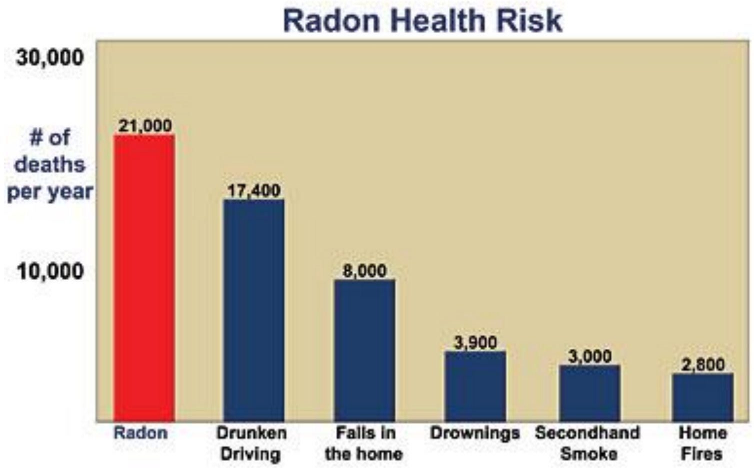
- Acute Doses:
  - Large amount of dose in a short period of time
  - If great enough, radiation sickness develops with symptoms shown in organs or systems with rapidly dividing cells (bone marrow, gastrointestinal tract); severity depends on dose
- Chronic Doses:
  - Small amount of radiation over a long period of time
  - Examples:
    - Background doses
    - Occupational doses
    - Medical and dental x-rays
  - *Human body handles a chronic dose better than an acute dose*

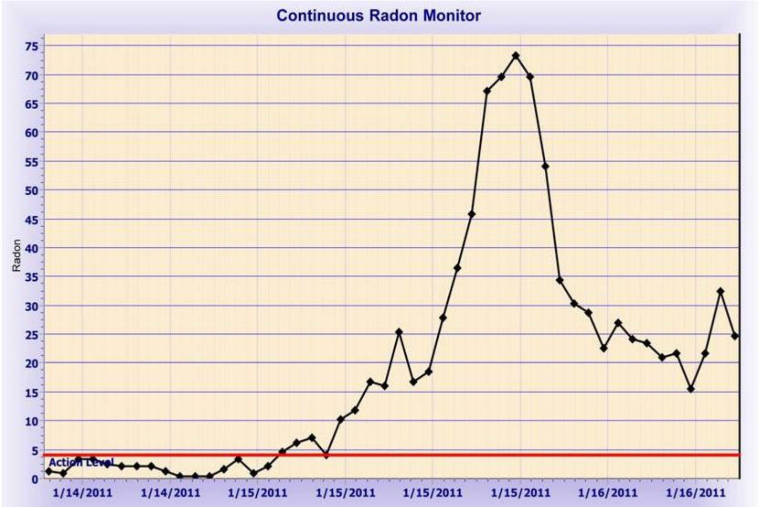
Where does radiation exposure come from?



Radon

- Radioactive decay products in rocks that are solids safely stay trapped in the rock.
- One of the decay products, radon, is a radioactive noble gas and lives long enough to migrate out of the rock into your basement air or well water.
- The EPA estimates that radioactive radon causes 21,000 deaths / year due to lung cancer. An indoor radon level of 4 pCi/liter = 150 Becquerels/m^3 is considered the "action threshold", above which corrective action should be taken.
- Does this mean that levels below 4 pCi/liter are safe? Not at all. At 2 pCi/liter, we just have half as many long-term cancer deaths, which is clearly not safe for the thousands of people who get lung cancer from radon exposure.





Radon level in this house increased dramatically from one day to the next, because furnace turned on.

Radiation Incidents

- Nuclear weapons testing 1945-1980
- Atom bomb attacks Japan 1945

- Chernobyl nuclear reactor accident 1986
- Fukushima nuclear reactor accident 2011

Clicker

The biological damage resulting from human exposure to radioactive materials is caused by

A. Thermal energy created by radioactive decay within biological cells.
B. Chemical reactions involving radioactive elements.
C. The ionizing effect of radioactive radiation.
D. Nuclear fission occurring within biological cells.
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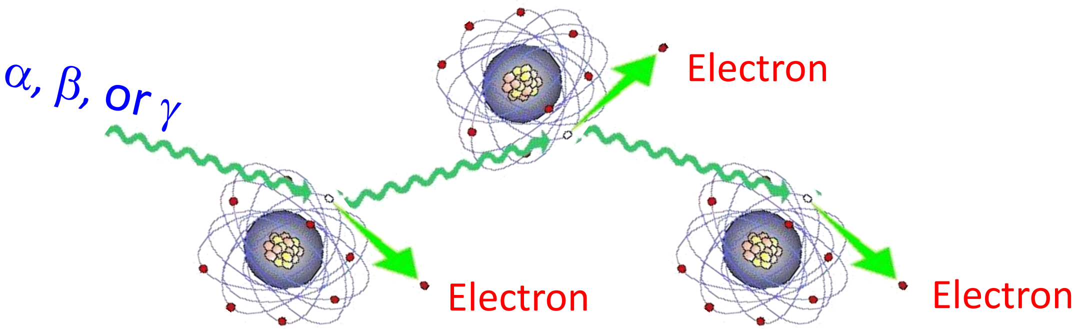
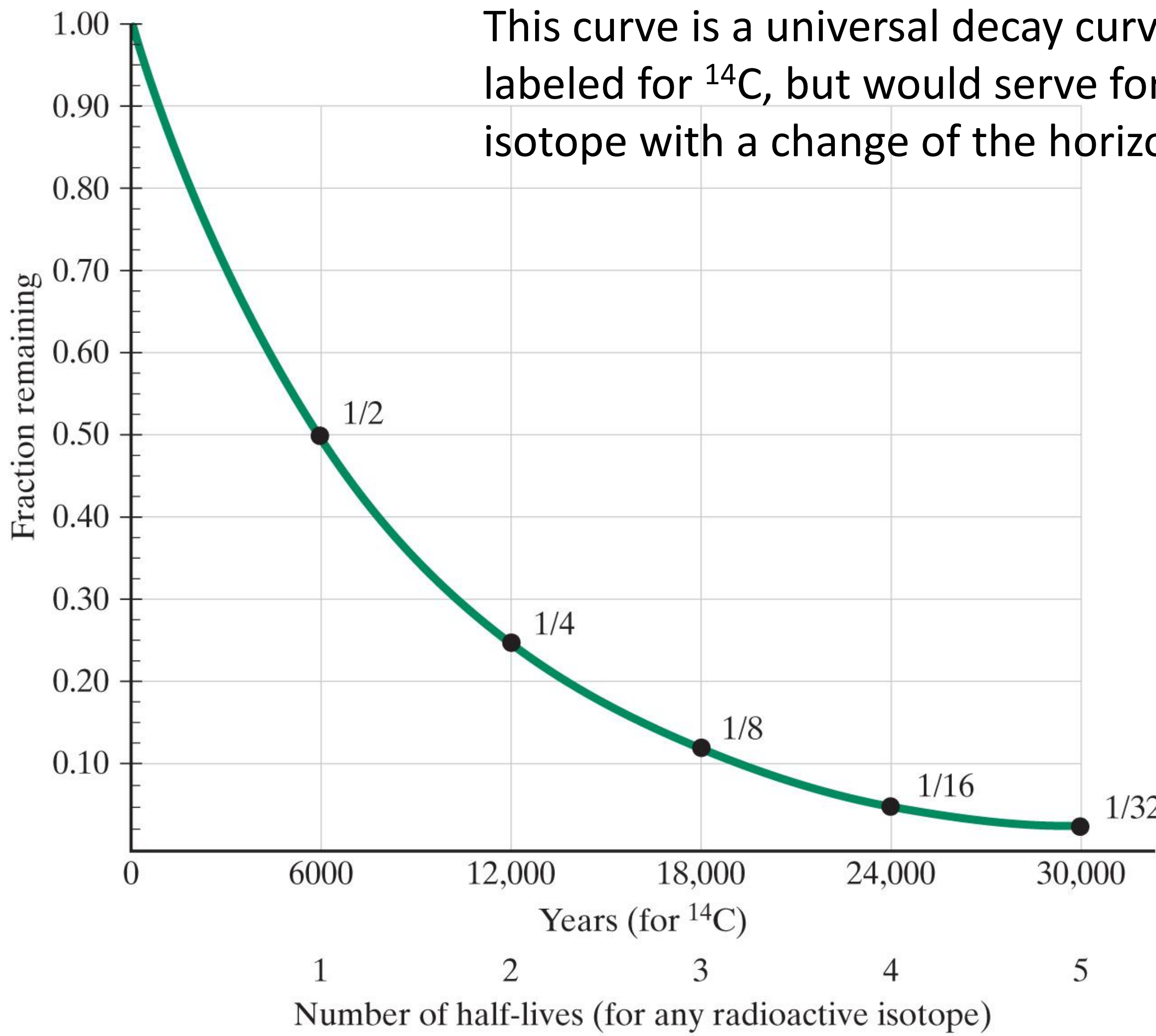


Radioactive Dating

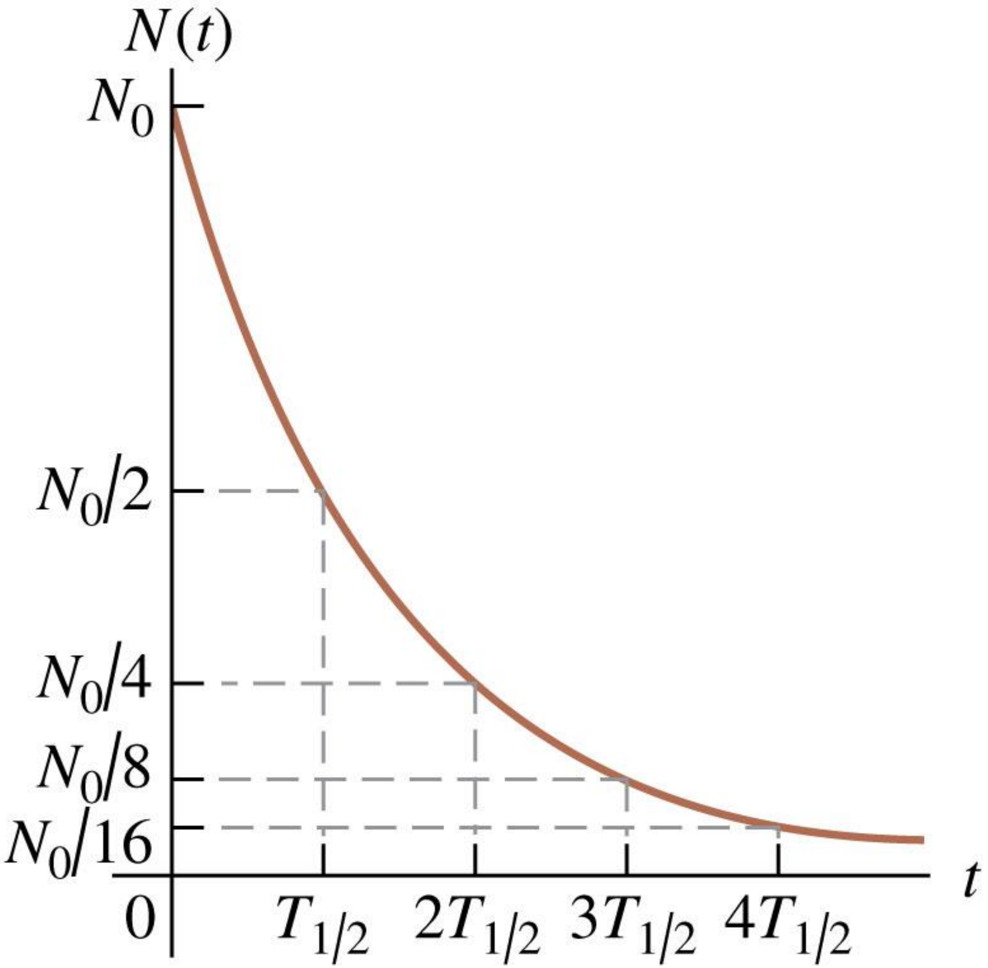
Half-Life with Dice

Half-life & Radioactive Dating

This curve is a universal decay curve. It is labeled for ^{14}C, but would serve for any other isotope with a change of the horizontal scale.



Half-Life



- Instead of measuring the number of "undecayed" nuclei, one can measure the radioactivity, i.e., the number of decays per second.
- The unit for decays is 1 Becquerel = 1 decay/s, but another common unit is the Curie, 1 Ci = 3.7×10^{10} Bq.

Half life

Definition:

The amount of time after which, on average, half of the radioactive atoms decay

Example:

We start with 24 g of an isotope having a half-life of 5 days.

- After 5 days: 12 g is left
- After 10 days: 6 g is left
- After 15 days: 3 g is left
- After 20 days: 1.5 g is left

iClicker

You accidentally eat some ^{11}C, which has a 20 minute half life. What fraction of the ^{11}C is left after 1 hour?

a) none

b) 1/2

c) 1/4

d) 1/8

e) who cares – you'll be dead.

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Radioactive Dating

Table 14.1

Half-life and decay process of several radioactive isotopes

Isotope	Name of element	Decay process	Half-life (approx.)
$^{14}_{6}C$	carbon	beta	6000 yr
$^{90}_{38}Sr$	strontium	beta	30 yr
$^{131}_{53}I$	iodine	beta	8 days
$^{214}_{84}Po$	polonium	alpha	0.000 16 s
$^{222}_{86}Rn$	radon	alpha	4 days
$^{235}_{92}U$	uranium	alpha	0.7×10^9 yr
$^{238}_{92}U$	uranium	alpha	4.5×10^9 yr
$^{239}_{94}Pu$	plutonium	alpha	24,000 yr

Which one could be useful for dating the first human settlements, say 5,000 years ago?

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Carbon Isotope Abundances

Carbon in CO_2 in air:

- ^{12}C: 99% (stable)
- ^{13}C: 1% (stable)
- ^{14}C: 1 part in 10^{11} (half-life of 6,000 yrs)

So all ^{14}C should be gone by now. Why isn't it?

- Because, in the atmosphere, high energy cosmic rays interact with air nuclei to produce neutrons. These neutrons then initiate the reaction

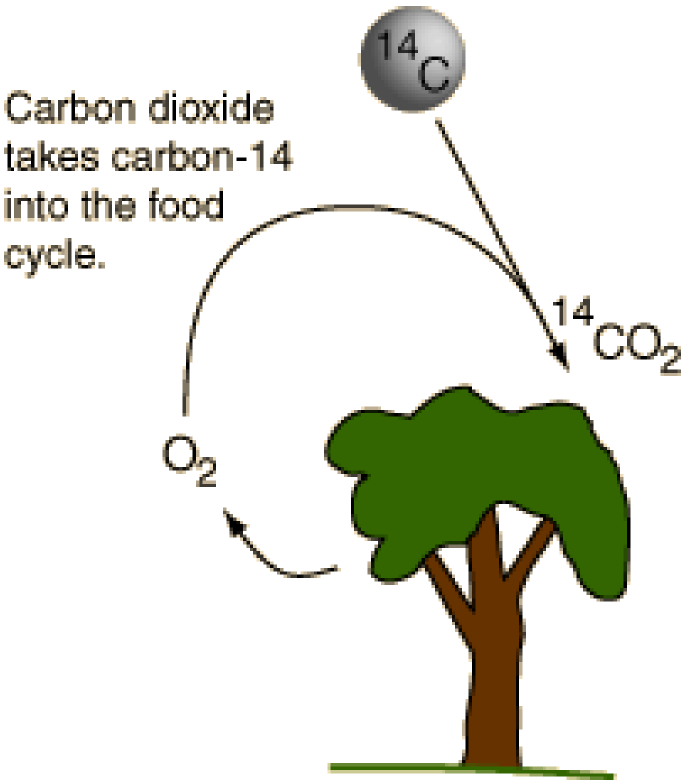
$$\text{neutron} + {}^{14}N \rightarrow {}^{14}C + \text{proton}$$

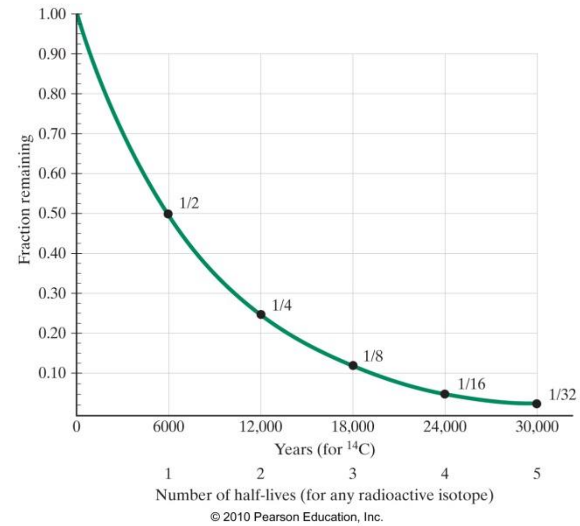
- In living organisms, the ^{14}C is continually being replenished.
- Once the organism dies, ^{14}C decay will reduce its abundance.

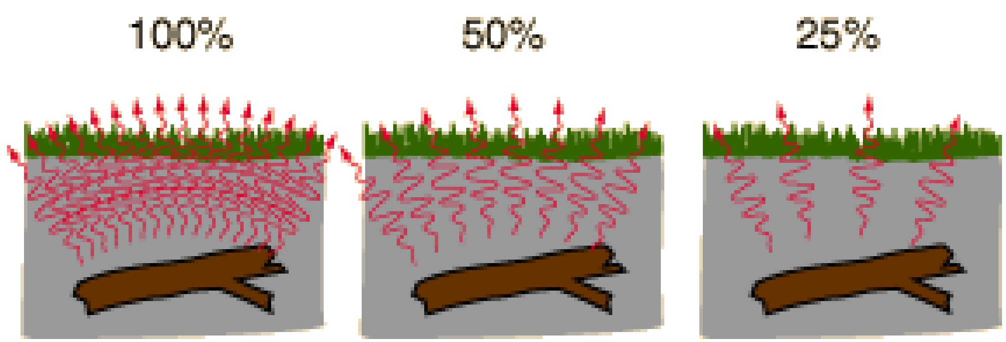
Radioactive Carbon Dating

- $^{14}C/^{13}C$ ratio in CO_2 in air is 10^{-9}
- All *living organisms* exchange C with CO_2 in air over its lifetime
- $^{14}C/^{13}C$ ratio in *living organisms* is 10^{-9}
- $^{14}C/^{13}C$ ratio in *dead tissues* is:
  - ✓ $10^{-9} \div 2$ after 6,000 years
  - ✓ $10^{-9} \div 4$ after 12,000 years
  - ✓ $10^{-9} \div 8$ after 18,000 years
  - ✓ $10^{-9} \div 16$ after 24,000 years
  - ✓ Etc.

Radioactive Carbon Dating







Age 0 yrs Age 6,000 yrs Age 12,000 yrs

Radioactive Dating

We need:

- An isotope with a half-life in the right range.
- But we also need a mechanism for isotope ratios to be disturbed – like ^{14}C
- Or another mechanism that lets us know something about the initial state, such as when a radioactive decay product accumulates in the sample (e.g. Uranium-Lead dating w/ 700 million year half life).

Clicker

An archaeologist digs up a bone that shows an average of one ^{14}C decay per minute per gram, which is about 10% of the rate in living organisms. Recalling that the ^{14}C half-life is 6,000 years, what is the approximate age of the bone?

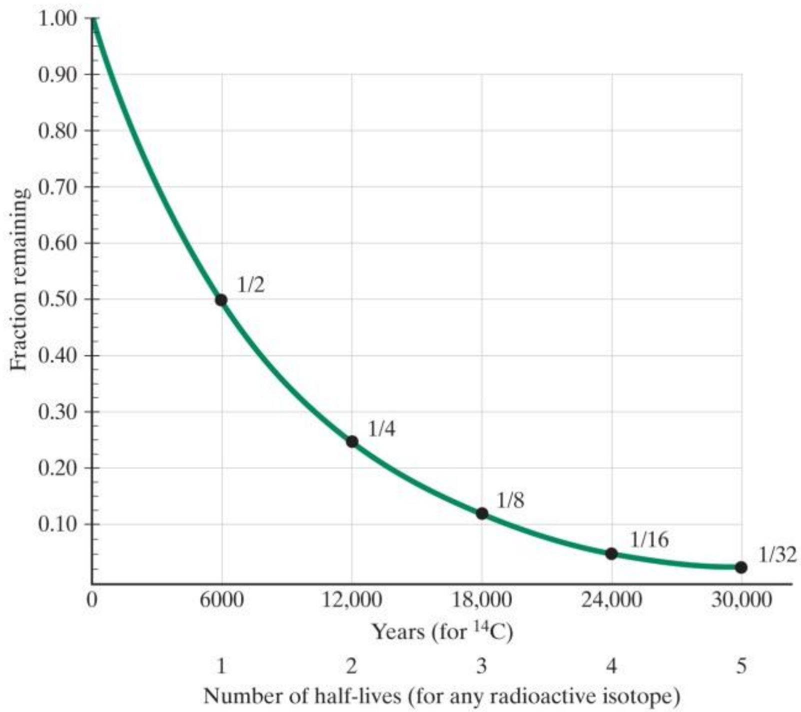
A) 600 years.

B) 6,000 years.

C) 13,000 years.

D) 19,000 years.

E) 60,000 years.



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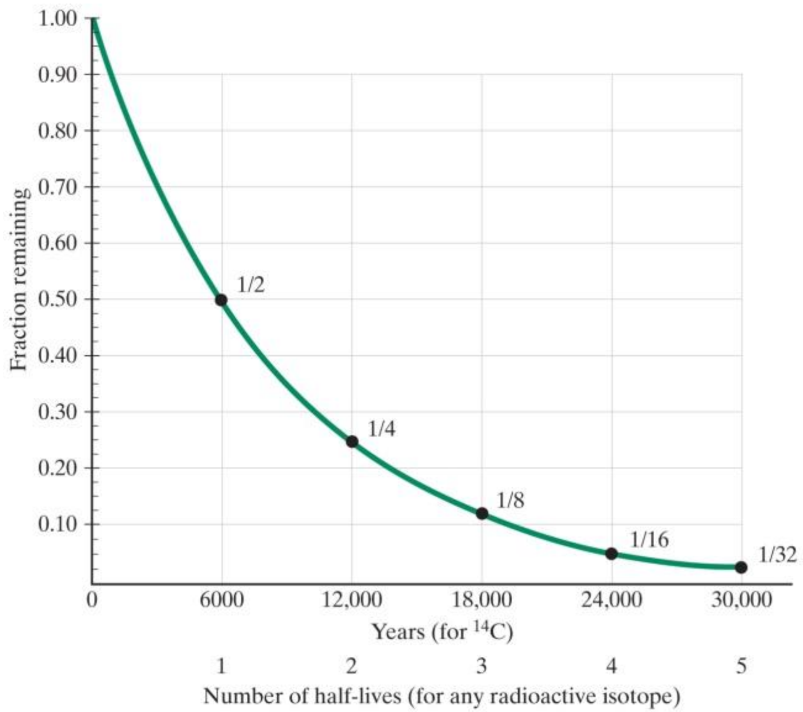

Nuclear Fusion and Fission

- Fission:
  - Nuclear power reactors.
  - Nuclear warheads.

- Fusion:
  - Energy of the stars.
  - “Thermonuclear” weapons.

Origin of the Words

Fusion:

- Metallurgists “fuse” two metals together to make an alloy (“put together”).
- Or “fusion cuisine” (different styles put together).

Fission:

- Think “fissure” (something that has been cracked apart).

Plot: rest mass/rest energy per particle for all nuclei (not to scale).

- Iron (mass number 56) is the most stable element.
- Lighter nuclei can give off energy when they fuse.
- Heavier nuclei can give off energy if they spit (fission).