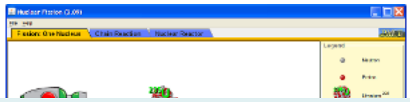
# Nuclear Weapons (and Energy)



- Graded long answers are in the black boxes in the help room (and there are lots of older homeworks that people should pick up!)

- We have one long answer without a name this week. … is that you?

mers
not to use radioactive glazed ceramics for food or drink use.

Phys 2130, Day 34:
Questions?
Nuclear Weapons and Energy

Reminders:
HW due Thurs…

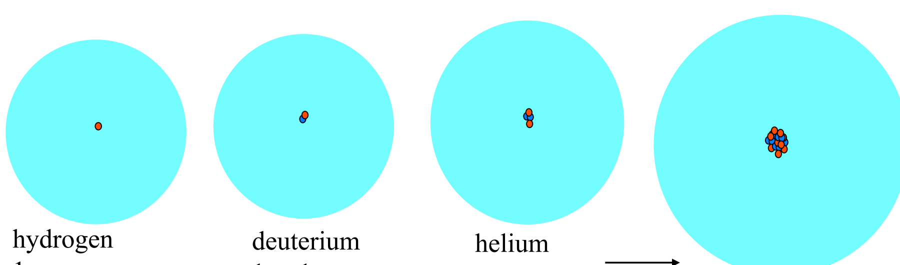
# Each element has different number of protons

Atom ingredients:

- Proton (**positive charge**) – charge = $1.6 \times 10^{-19}$ Coulombs
  mass = $1.66 \times 10^{-27}$ kg.
- Neutron (**no charge**) – no charge
  mass = $1.66 \times 10^{-27}$ kg.



Electron (**negative charge**) – charge = $-1.6 \times 10^{-19}$ Coulombs
mass = $9.10 \times 10^{-31}$ kg



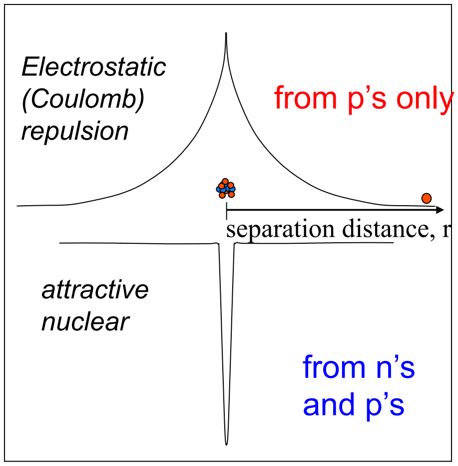
hydrogen
1 p

deuterium
1 p, 1n

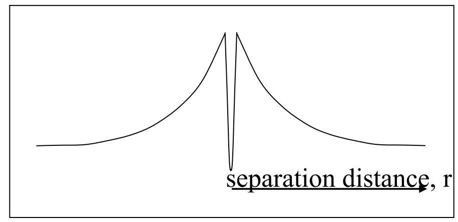
helium
2 p, 2 n

Uranium 238
92 p, 146 n

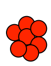
# Potential energy curve for atoms



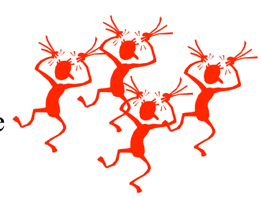

**Superposition - real nucleus**

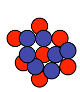



## Stabilizing effect of neutrons in the nucleus …
## why do you need them?

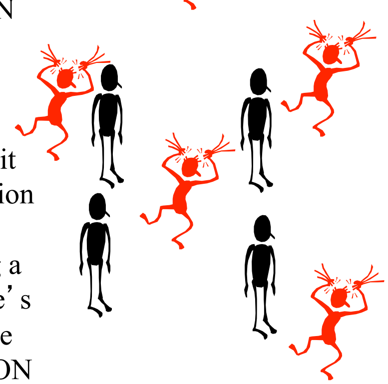


If only have big bunch of protons, proton repelling each other a whole bunch. Like putting a bunch of people who find each other repulsive in same room… UNSTABLE SITUATION





Add neutrons then space protons a bit away from each other, proton repulsion goes down a bit but still have strong nuclear binding forces. Like putting a bunch of neutral people between one's that find each other repulsive in same room… MORE STABLE SITUATION

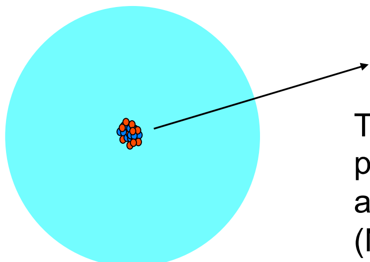


# Radioactive decay

- Proton (**positive charge**)
- Neutron (**no charge**)

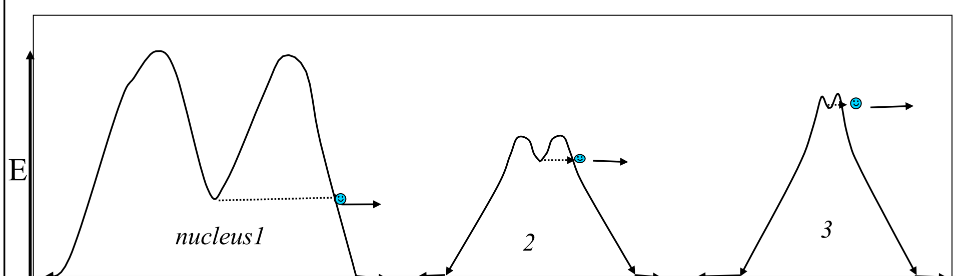
Radon-222
86 protons,
136 neutrons

In alpha-decay, an alpha-particle is emitted from the nucleus.



This raises the ratio of neutrons to protons … makes for a more stable atom.
(Neutron are neutral.. no coulomb repulsion, but nuclear force attraction)

# Tunneling probability and energy release




hard- takes long time, billions of years!

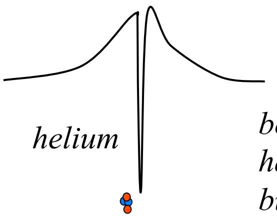
medium

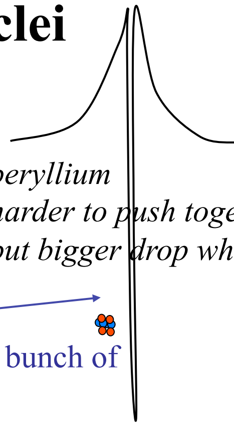
easy!, happens in millionths of a second!

How much energy released?
(A) 1 most, 2 second, 3 least
(B) 2 most, 1, 3 least
(C) 3 most, 2, 1 least
(D) 3 most, 1, 2 least

energy is difference from bottom of crater to outside.
3 is most, 2 second, 1 is least

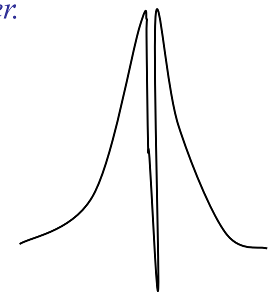
# Atomic nuclei



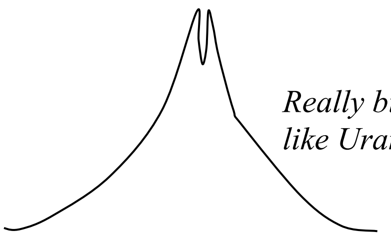




harder to push together, but bigger drop when do.

*Gets deeper until iron (26 P, 30 N) less deep if bigger.*



Really stable: Have to add a whole bunch of energy to break up!

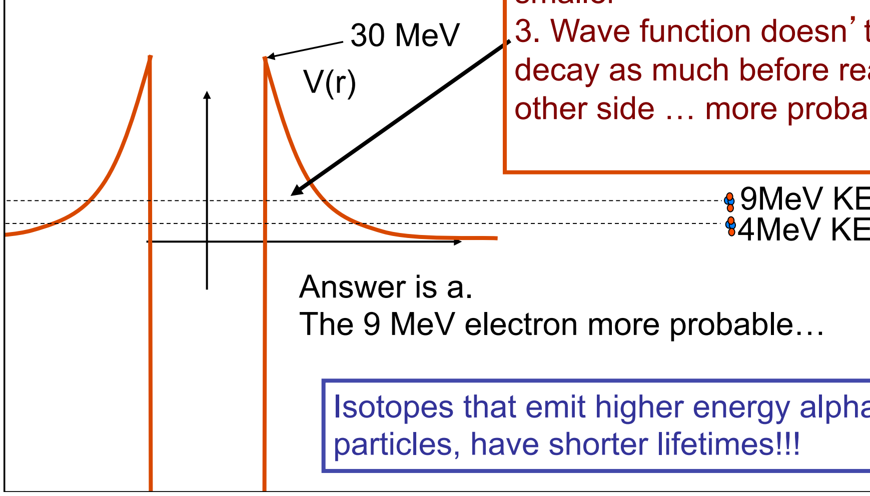


*Really big nucleus, >100 P, >100 N, like Uranium or plutonium*

Observe a particles from **different isotopes (same protons, different neutrons),** exit with different amounts of energy.

$$\alpha = \sqrt{\frac{2m}{\hbar^2}(V - E)}$$

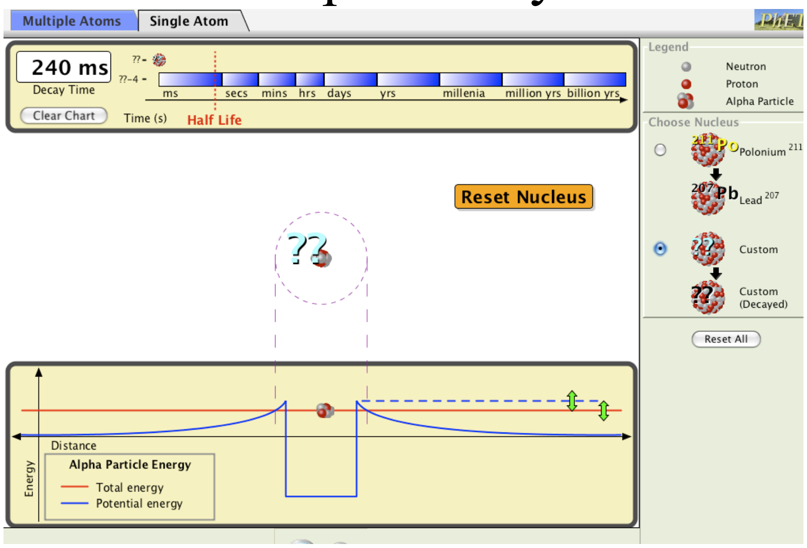
1. Less distance to tunnel,
2. Decay constant always smaller
3. Wave function doesn't decay as much before reaches other side … more probable!




Answer is a.
The 9 MeV electron more probable…

Isotopes that emit higher energy alpha particles, have shorter lifetimes!!!

# Alpha decay

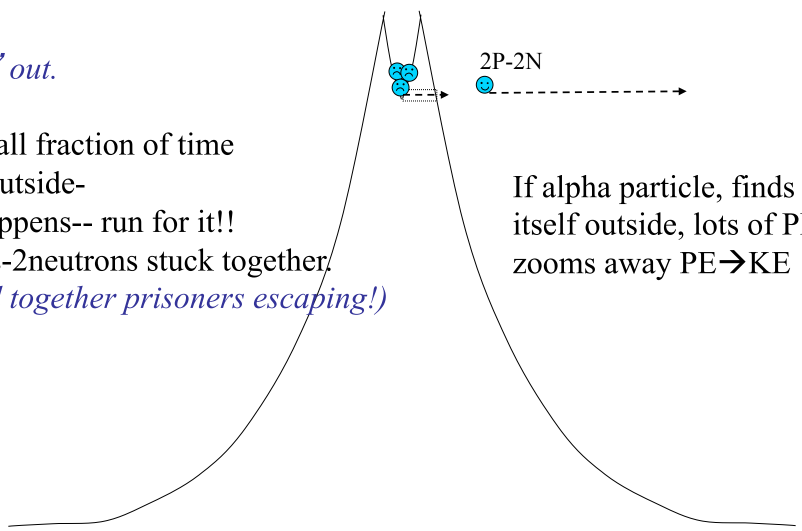



**Nuclear decay- one kind of nucleus changes into another.**

*alpha decay, (beta decay), induced fission*

**a. alpha decay- alpha particle = 2p and 2n. They escape together. Most radioactivity is this type (e.g. radon).**

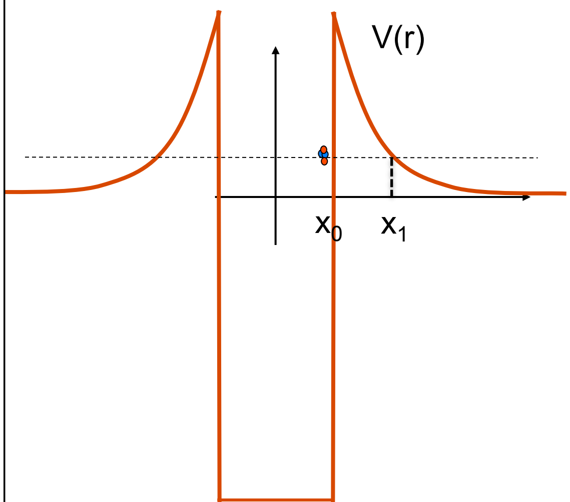
*"tunnel" out.*




Very small fraction of time
appear outside-
when happens-- run for it!!
2protons-2neutrons stuck together
*(chained together prisoners escaping!)*

If alpha particle, finds itself outside, lots of PE, zooms away PE→KE

# Quantum Tunneling: α-decay



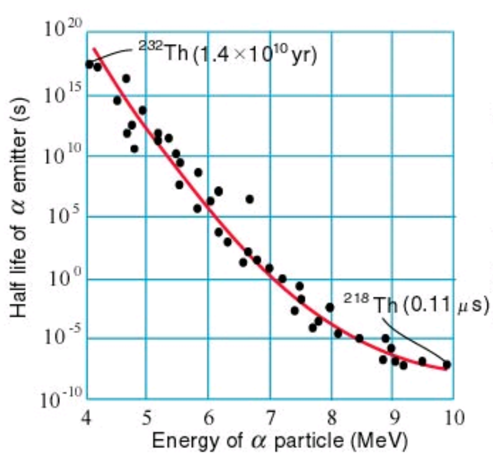

For square well:

$$P \approx e^{-2\alpha D}$$

For our alpha-decay model potential:

$$P \approx e^{-\int_{x_0}^{x_1} 2\alpha(x)\,dx}$$

# Lifetimes of unstable nuclei




Lifetimes vary by orders of magnitude:

E = 4 MeV → $10^{23}$ s

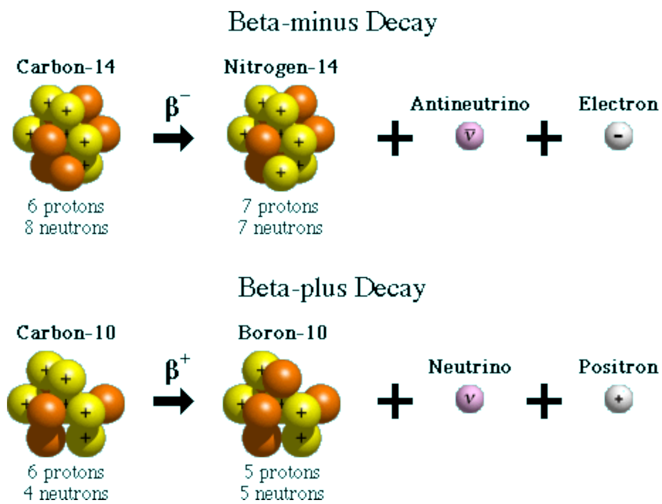
E = 6 MeV → $10^{8}$ s

E = 9 MeV → $10^{-4}$ s

Was hard to understand how one common process could lead to such different lifetimes

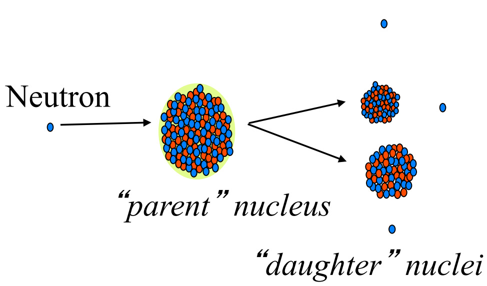
Huge success of model !

# Other forms of decay: β-decay



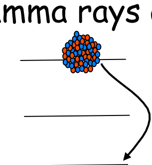

## B. Radioactive decay-fission

### Neutron Induced fission- key to atomic bombs



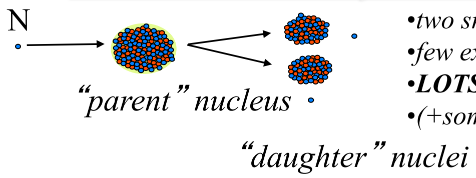

- *two smaller nuclei*
- *few extra free neutrons*
- ***LOTS OF ENERGY!!***
- *(+sometimes other bad stuff)*

"daughter" nuclei – come out in *excited* nuclear energy state …. Give off gamma rays as drop to lower energy.

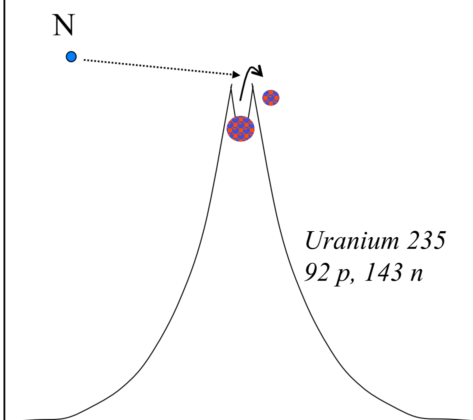


Jumps down in energy …
Gives off gamma ray…
VERY HIGH ENERGY PHOTON

# Neutron Induced fission- key to atomic bombs

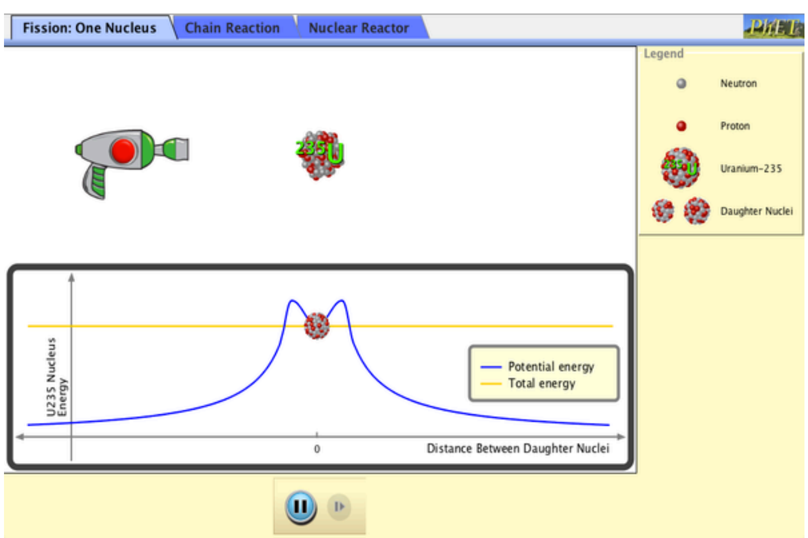



- *two smaller nuclei*
- *few extra free neutrons*
- ***LOTS OF ENERGY!!***
- *(+sometimes other bad stuff)*



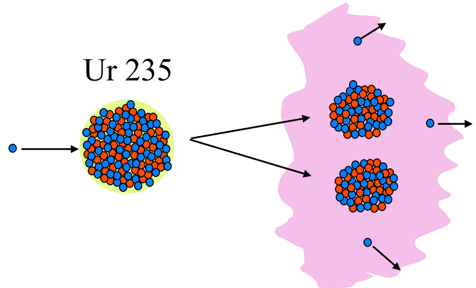

Neutron absorbed →
Excites U235 nucleus up above potential barrier →
Splits into two smaller nuclei…
which zoom apart due to electrostatic repulsion!

simulation



neutron induced fission

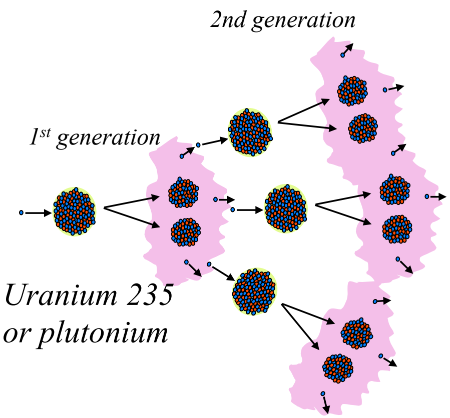
*Fermi first did it, Lise Meitner and "helpers" figured out what was happening.*




If don't get swallowed the 3 free neutrons can go induce more fission.

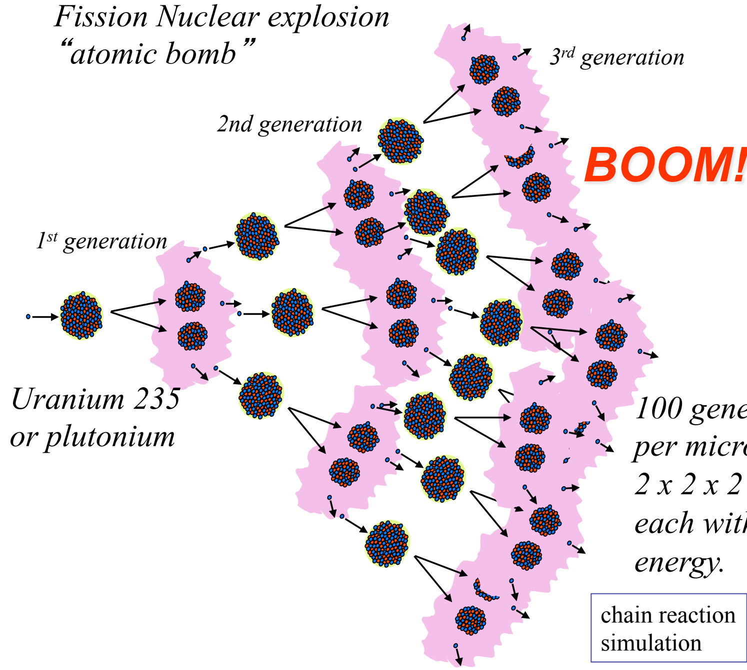
**Chain reaction:** neutrons making fission that makes more neutrons, that makes more fission that makes more neutrons, that makes more fission that makes more neutrons, that makes more fission that makes more neutrons, that makes more fission that makes more neutrons, that makes more fission that makes more neutrons, that makes more

*Fission Nuclear explosion "atomic bomb"*




*Uranium 235 or plutonium*

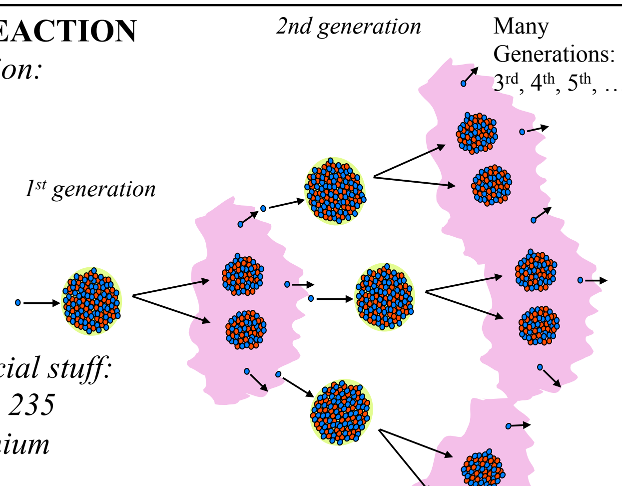
*Fission Nuclear explosion*
*"atomic bomb"*




*100 generations per microsecond!*
*2 x 2 x 2 ….x2 fissions each with* ***LOTS*** *of energy.*

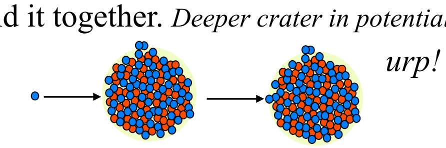
chain reaction simulation

**BACK TO CHAIN REACTION**
*Fission Nuclear explosion:*
*"atomic bomb"*

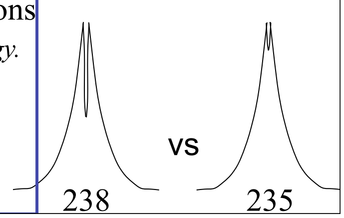



*Very special stuff:*
*Uranium 235*
*or plutonium*

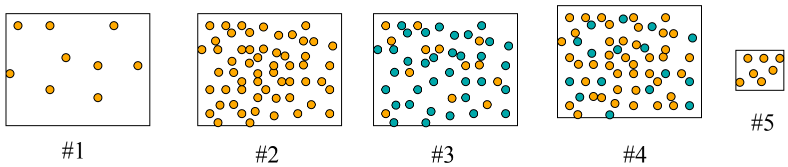
**Why Ur 235 not 238?** U 238 has 3 extra neutrons help hold it together. *Deeper crater in potential energy.*




*Eats extra neutrons!*



U235 and U238 atoms are placed into a container, which are likely to result in a chain reaction (resulting in explosion) when a free neutron triggers fission of one of the U235:

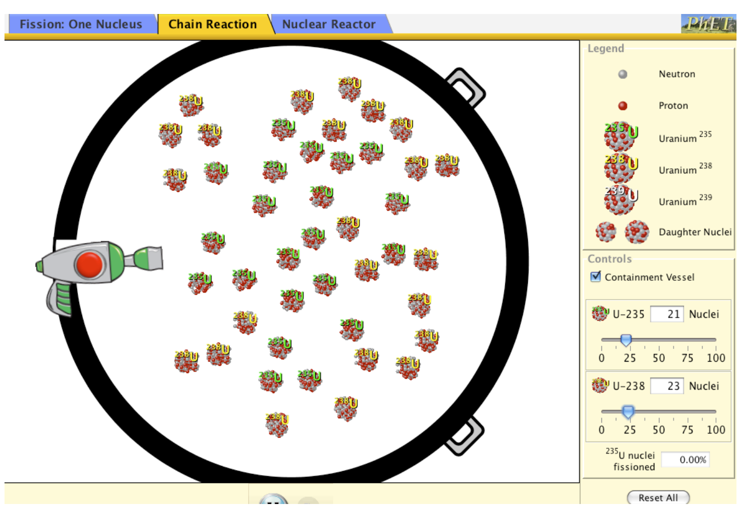



a. #2 only
b. #1, #2, and #5
c. #2 and #4
d. #2, #3, and #4
e. #2, #4, and #5.

Lots of uranium in the ground… why not just blow up?

Correct answer is c. (#2 and #4) Analysis:
#1 is too sparse .. most neutrons will leave box before hitting another U235.
#2 is good.. Pure U235, densely packed, large package
#3 has too many U238's… more U238's than 235's. Free neutrons more likely to be absorbed by 238's than to hit and fission another 235.
#4 is OK … More U235's than 238's, still densely packed, large package
#5 is too small of package … neutrons likely to escape package before hitting another U235.

# A useful simulation

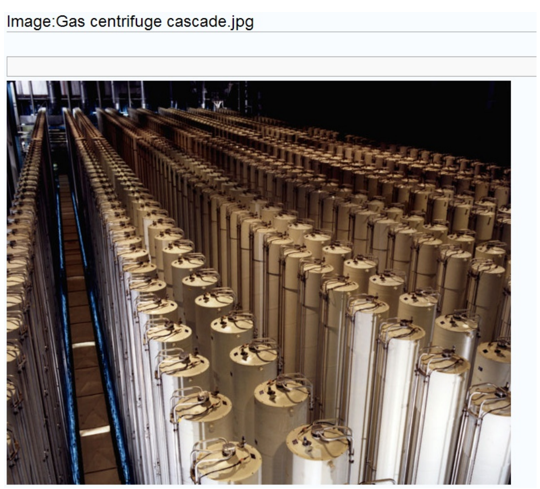



http://phet.colorado.edu/simulations/sims.php?sim=Nuclear_Fission

## How to get $^{235}$U?

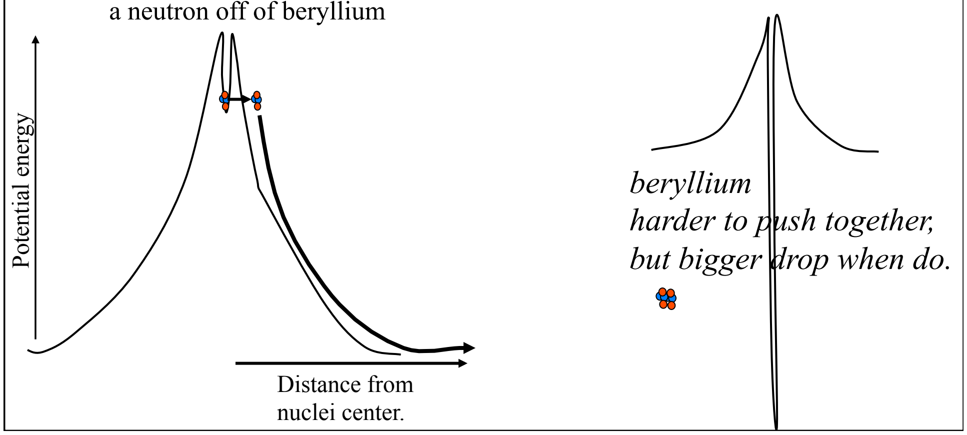
The isotope $^{235}$U (0.7%) may be separated from $^{natural}$U by gaseous diffusion or centrifuges in large plants. The chemical compound used is $UF_6$, a corrosive gas.

## Gas centrifuge farm



Why use Beryllium as a neutron source for triggering fission bomb if so stable?
answer: good that stable… doesn't give off a neutron until you do something
What do you need to do to make it give off a neutron? …
Bombard with alpha particles from Polonium decay…

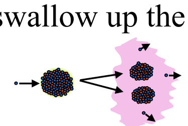
Polonium (84 p's, 125 n's):
Alpha particle (2 protons, 2 neutrons) tunnels out of well…. Zooms off and knocks a neutron off of beryllium



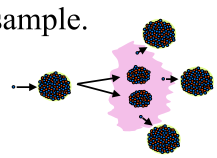

# Recipe for fission bomb.

1. Find neutron induced fissionable material that produces bunch of extra free neutrons when fissions.

*2. Sift it well to remove all the other material that will harmlessly swallow up the extra neutrons. (THE HARDEST STEP.)



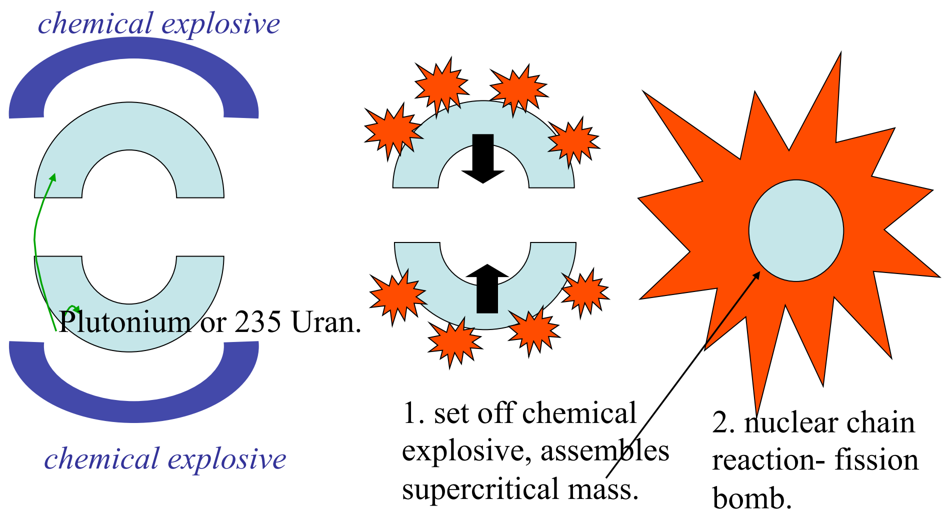
3. Assemble "supercritical mass", really fast!. Need enough stuff that the neutrons run into other nuclei rather than just harmlessly leaving sample.



*If your mass tends to melt with a small fizzle you are not assembling fast enough to be supercritical. Put together faster.*

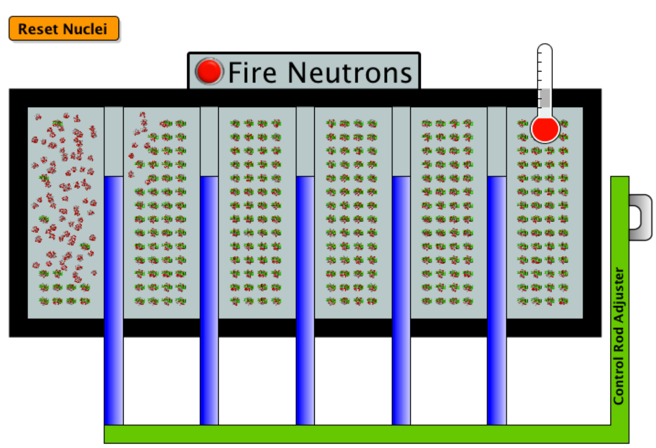
4. Let sit for 1 millionth of a second- will bake itself!

## *Fission bomb (basic picture)*

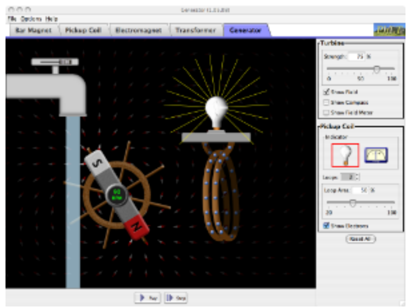



## Nuclear Reactor Sim

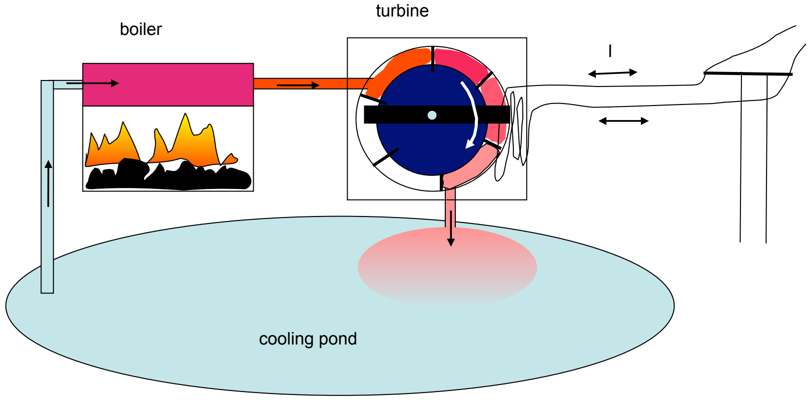
http://phet.colorado.edu/en/simulation/nuclear-fission



# Generator Simulation



http://phet.colorado.edu/en/simulation/generator

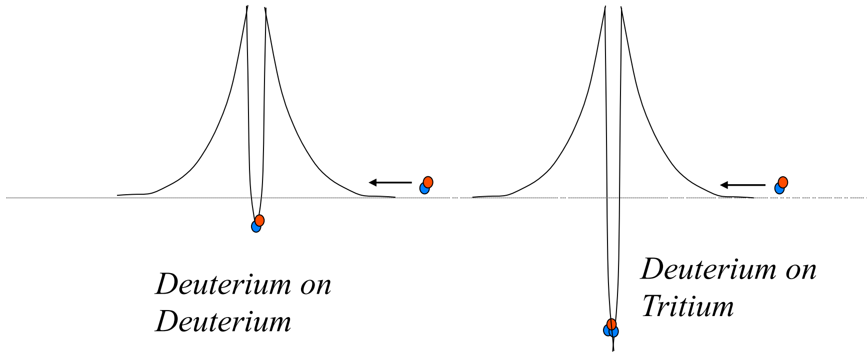



All about turning the magnet / turbine… can do this with:

- -Coal (produce steam)
- -Nuclear (produce steam)
- -Wind (directly rotate)
- -Ocean waves (directly rotate)

## Fusion bomb or "hydrogen bomb"

Basic process like in sun. Stick small nuclei together.




Which will release more energy during fusion?

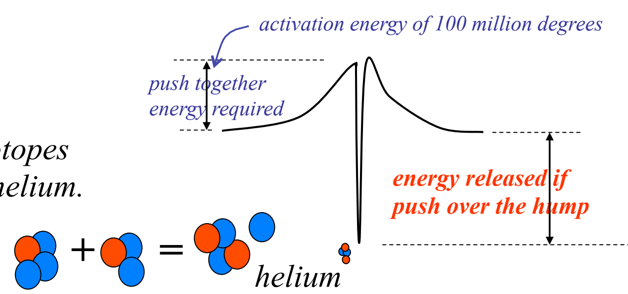
a. Deuterium combining with deuterium
b. Deuterium combining with tritium

Answer is b. Incoming deuterium particle has comparatively more potential energy!

## Fusion bomb or "hydrogen bomb"

Basic process like in sun. Stick small nuclei together.

*Stick hydrogen isotopes together to make helium.*

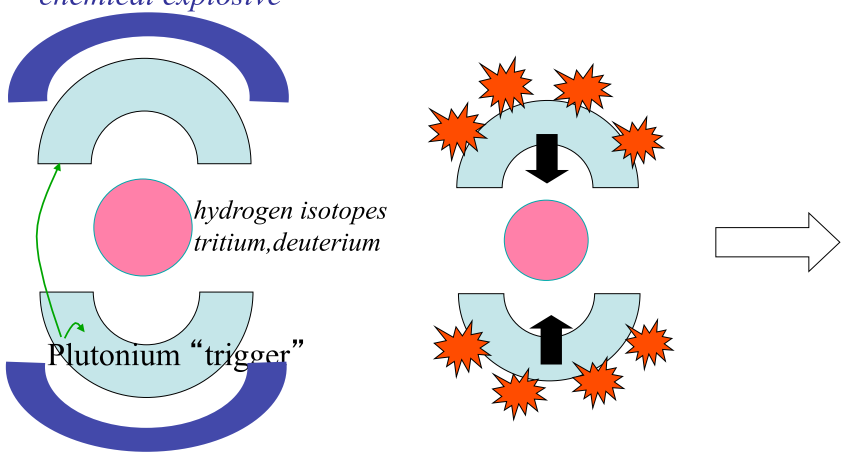



Simple if can push hard enough- just use sun or fission bomb.
More energy per atom than fission. Can use LOTS of hydrogen.

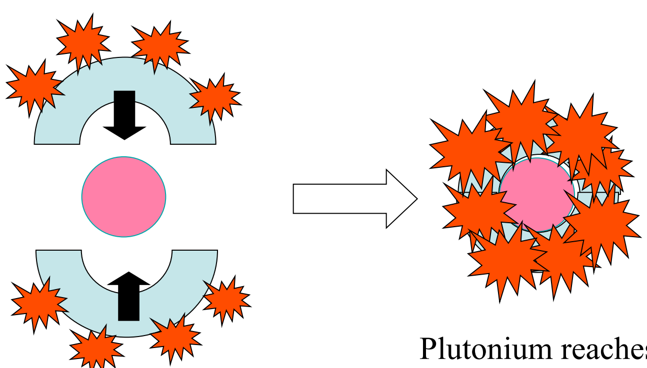
***⇒End up with GIGANTIC bombs***

**1000 times bigger than first fission bombs**

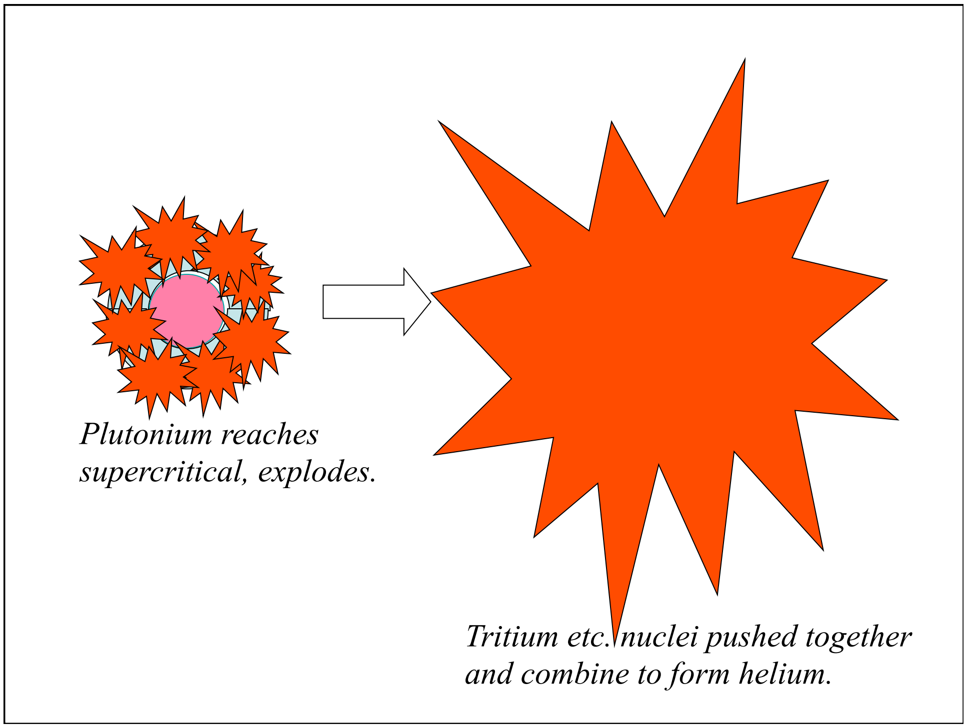
## *Fusion bomb (simple picture)*




Shaped plutonium and assembled bombs at Rocky Flats.



Plutonium reaches supercritical, explodes. *(fission bomb)*




# Energy:

1 fission of Uranium 235 releases:
$\sim 10^{-11}$ Joules of energy

1 fusion event of 2 hydrogen atoms:
$\sim 10^{-13}$ Joules of energy

Burning 1 molecule of TNT releases:
$\sim 10^{-18}$ Joules of energy

1 green photon:
$\sim 10^{-19}$ Joules of energy

Dropping 1 quart of water 4 inches ~ 1J of energy
Useful exercise… compare this volume of TNT, H2, and U235

In the first plutonium bomb a 6.1 kg sphere of plutonium was used and the explosion produced the energy equivalent of 22 ktons of TNT = $8.8 \times 10^{13}$ J.

17% of the plutonium atoms underwent fission.

How long would this power your house?

How much power (energy / sec) do you use?

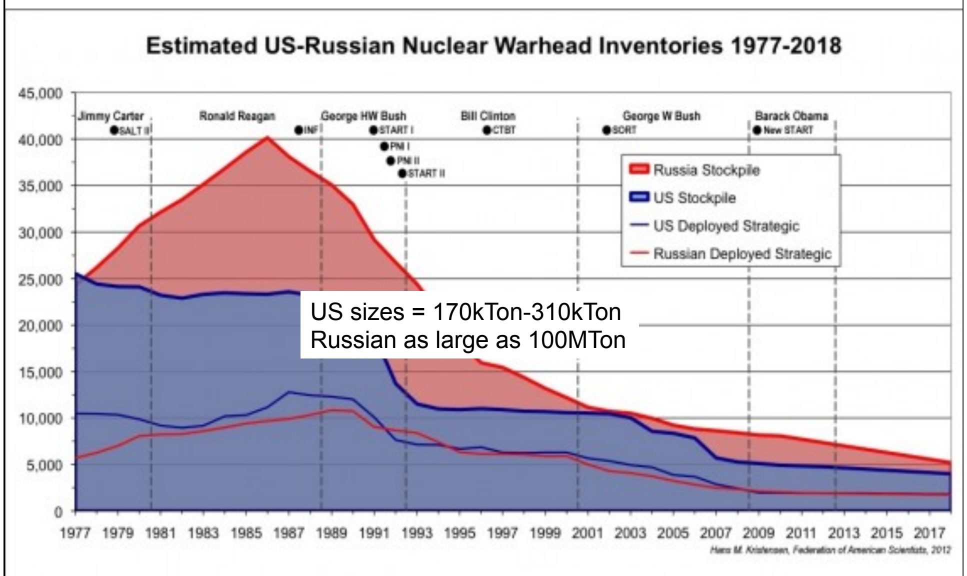
e.g. 10 x 100W lightbulbs? Or 100x 100W?

(use your energy bill)

1000W = 1000 J / sec.

$8.8 \times 10^{13}$ J / (1000 J /s ) = ?? sec

# US Nuclear weapons



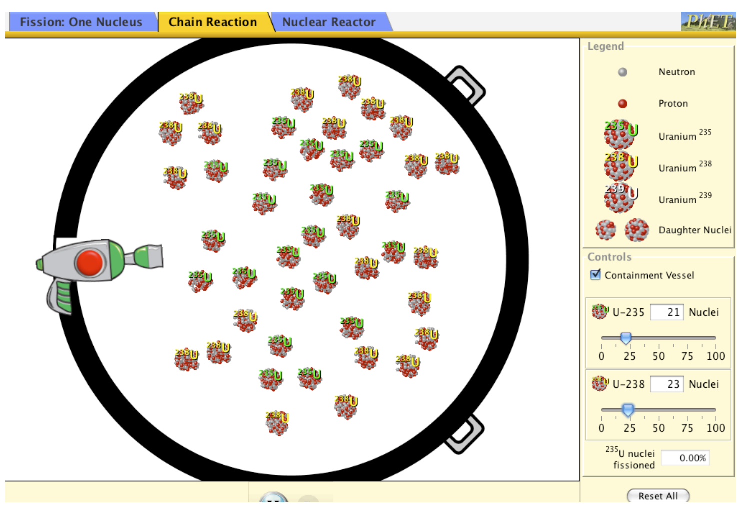
*Fission bomb-* ***chain reaction, hideous amounts of energy comes off as heat and high energy particles (electrons, neutrons, x-rays, gamma rays) "Radiation". Heats up air that blows things down.***

In atomic bomb, roughly 20% of Pl or Ur decays by induced fiss. This means that after explosion there are

a. about 20% fewer atomic nuclei than before with correspondingly fewer total neutrons and protons,
b. 20% fewer at. nucl. but about same total neut. and protons.
c. about same total neutrons and protons and more atomic nuclei,
d. almost no atomic nuclei left, just whole bunch of isolated Neut.s and prot.s.,
e. almost nothing of Ur or Pl left, all went into energy.

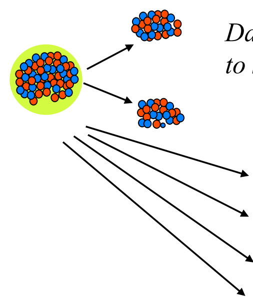
*ans. c. Makes and spreads around lots of weird radioactive "daughter" nuclei (iodine etc.) that can be absorbed by people and plants and decay slowly giving off damaging radiation.*
*Lots of free neutrons directly from explosion can also induce radioactivity in some other nuclei.*

# A useful simulation




http://phet.colorado.edu/simulations/sims.php?sim=Nuclear_Fission

## Radioactive materials and "radiation"



*Daughters often have too few neutrons*
*to stick together, so radioactive, divide more.*

Other bad/energetic stuff that comes out.

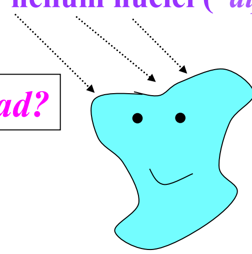
Neutrons

**electrons (*"beta particles"*)**

**photons (*"gamma rays"*)**

**helium nuclei (*"alpha particles"*)**

***Why radiation bad?***



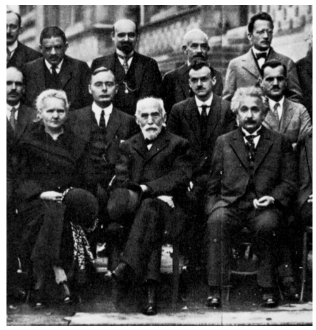
*Jocell*

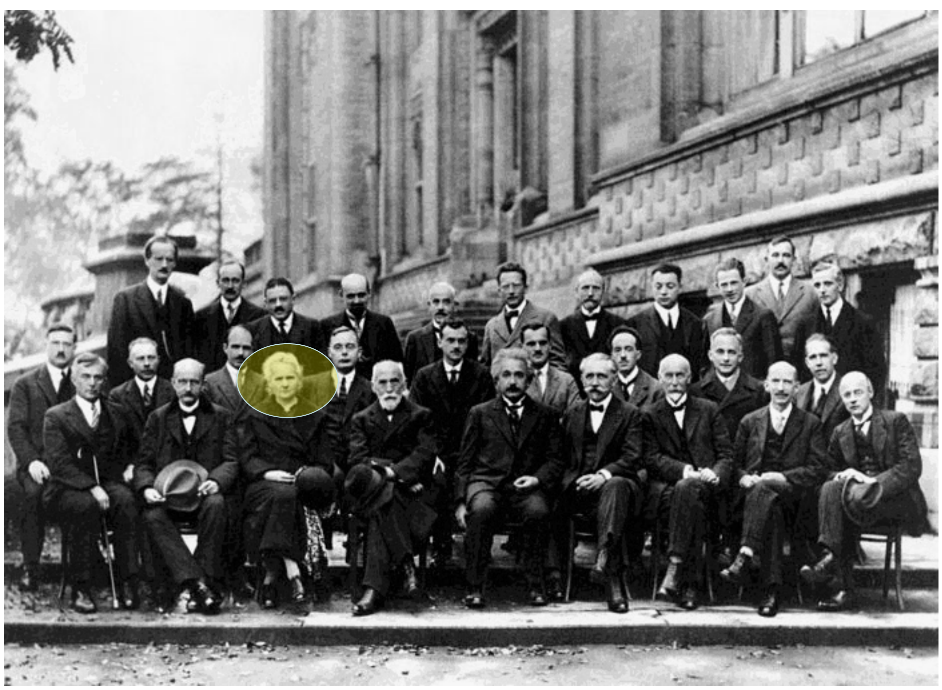
# Measuring "Radioactivity" & the Discovery of Radium and Polonium

"One of our joys was to go into our workroom at night; we then perceived on all sides the feebly luminous silhouettes of the bottles or capsules containing our products. It was really a lovely sight and one always new to us. The glowing tubes looked like faint, fairy lights."

-Marie Curie,
Nobel Prize Physics 1903,
Nobel Prize Chemistry 1911

# Curie and Einstein

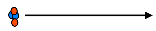




**Alpha particles: helium nuclei**

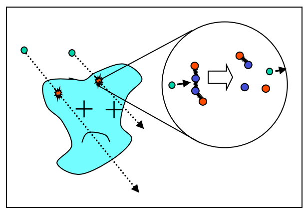
- most of radiation is this type
- common is Radon (comes from natural decay process of $U^{238}$), only really bad because Radon is a gas .. Gets into lungs, if decays there bad for cell.

In air: Travels ~2 cm ionizing air molecules and slowing down …



eventually turns into He atom with electrons

If decays in lung, hits cell and busts up DNA and other molecules:

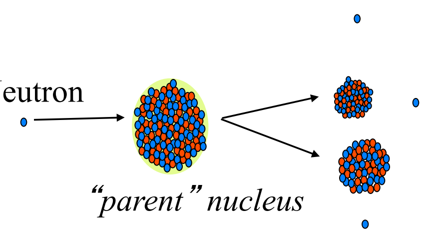


Usually doesn't get far -- because it hits things

**Beta particles:**

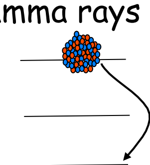
energetic electrons … behavior similar to alpha particles, but smaller and higher energy

# *Sources of Gamma Radiation*




- *two smaller nuclei*
- *few extra free neutrons*
- ***LOTS OF ENERGY!!***
- *(+sometimes other bad stuff)*

"daughter" nuclei – come out in *excited* nuclear energy state …. Give off gamma rays as drop to lower energy.

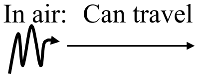


Jumps down in energy …
Gives off gamma ray…
VERY HIGH ENERGY PHOTON

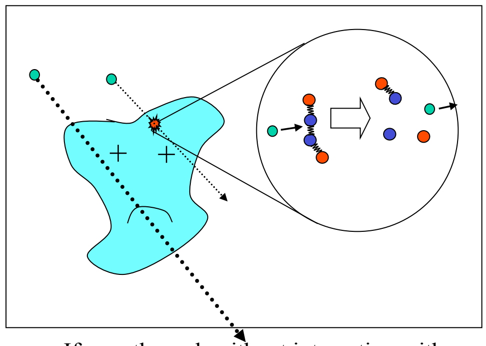
**gamma rays: high-energy photons**

- So high energy can pass through things (walls, your body) without being absorbed, but if absorbed really bad!

In air: Can travel long distances until absorbed

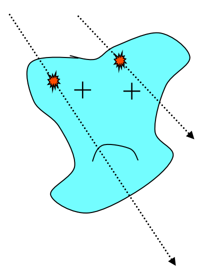


In body, *if* absorbed by DNA or other molecule in cell …
damages cell… can lead to cancer.



Most likely

If pass through without interacting with anything in cell then no damage.



*Also break DNA → cancer*

But also can cure cancer-
Concentrate radiation on
cancer cells to kill them.

# An odd world…

You find yourself in some diabolical plot where you are given an alpha ($\alpha$) source, beta ($\beta$) source, and gamma ($\gamma$) source. You must eat one, put one in your pocket and hold one in your hand. You …

a) $\alpha$ hand, $\beta$ pocket, $\gamma$ eat

b) $\beta$ hand, $\gamma$ pocket, $\alpha$ eat

c) $\gamma$ hand, $\alpha$ pocket, $\beta$ eat

d) $\beta$ hand, $\alpha$ pocket, $\gamma$ eat

e) $\alpha$ hand, $\gamma$ pocket, $\beta$ eat

$\alpha$ - very bad, but easy to stop -- your skin / clothes stop it
$\beta$ - quite bad, hard to stop -- pass into your body -- keep far away
$\gamma$- bad, but really hard to stop--- rarely rarely gets absorbed
Me--- I pick (d)---

# Results of radiation

**~4,000 counts/min = .002 Rem/hr**

dose in rem = dose in rad x RBE factor (relative biological effectiveness)

RBE = 1 for $\gamma$ , 1.6 for $\beta$, and 20 for $\alpha$.

A rad is the amount of radiation which deposits 0.01 J of energy into 1 kg of absorbing material.

| source/situation | dose | effect |
|---|---|---|
| neutron bomb blast | >100,000 rem | immediate death |
| Chernobyl firefighter | 400 rem | 50% probability of death within 30 days |
| space shuttle astronaut | 25 rem | due to increased cosmic ray exposure |
| accidental exposure | 10 rem | blood changes barely detectable |
| max. allowed exposure for radiation workers | 5 rem over 1 year | no blood changes detectable, negligible increased risk of cancer. |
| radon exposure (avg. US) | 200 mrem = 0.2 rem/yr | probably none |
| other terrestrial sources | 40 mrem/year | probably none |
| cosmic radiation (sea level) | 30 mrem/ year | probably none |
| single chest x-ray | 20 mrem | probably none |
| nuclear fallout+ | 3 mrem/year | probably none |
| nuclear power plant leakage | 0.01 mrem/year | probably none |
| total average dose (US citizens) | 350 mrem/year | probably none |

+ primarily due to atmospheric testing of nuclear weapons by US and USSR in the 50's and early 60's, prior to the nuclear test-ban treaty which forbid above-ground testing.