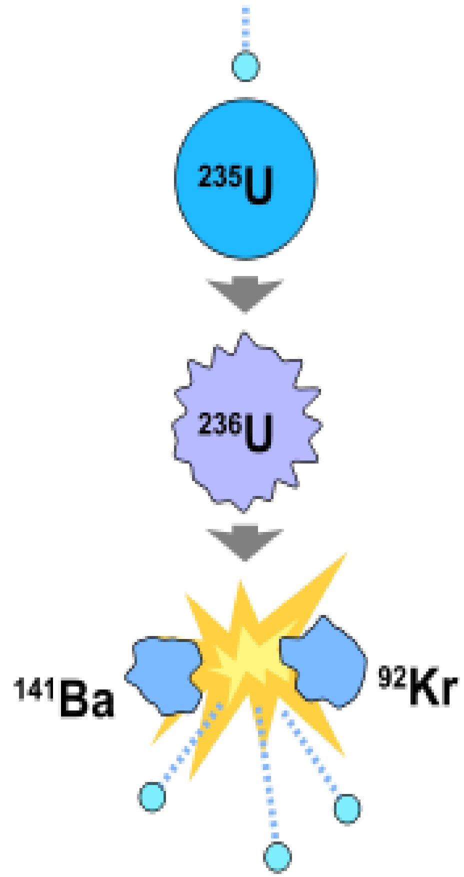
1938年底

核分裂



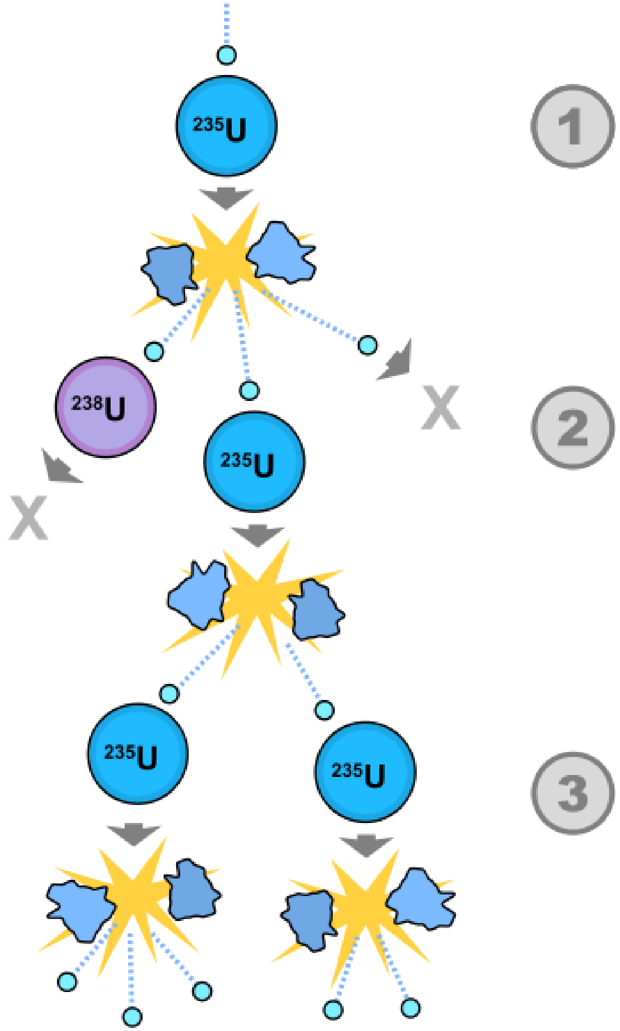
$E=mc^2$

Otto Hahn 1879-1968

1944 Nobel Chemstry Prize

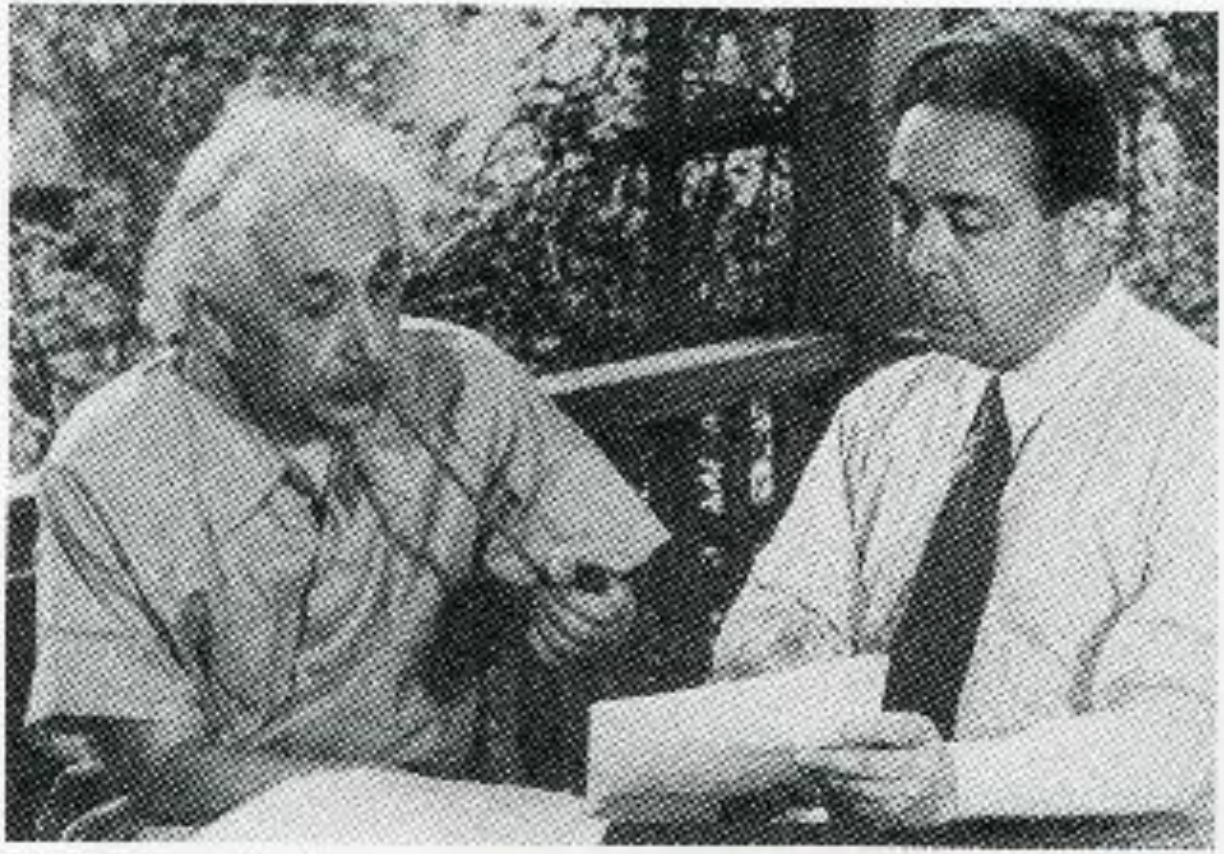
An induced fission reaction. A slow-moving neutron is absorbed by the nucleus of a uranium-235 atom, which in turn splits into fast-moving lighter elements (fission products) and three free neutrons.

The total rest masses of the fission products (**Mp**) from a single reaction is less than the mass of the original fuel nucleus (**M**). The excess mass **Δm** = **M** – **Mp** is the invariant mass of the energy that is released as photons (gamma rays) and kinetic energy of the fission fragments, according to the mass-energy equivalence formula $E = mc^2$.

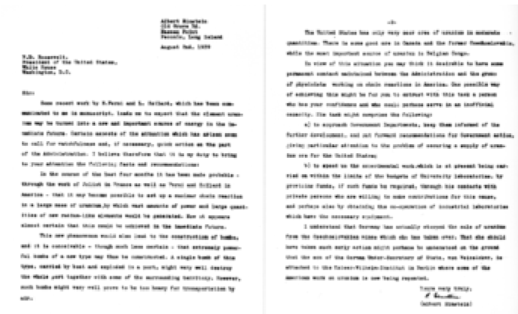


Chain reactions

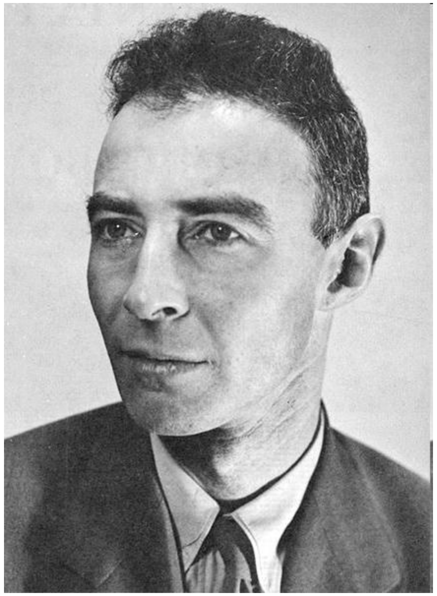
A schematic **nuclear fission** chain reaction. 1. A uranium-235 atom absorbs a neutron and fissions into two new atoms (fission fragments), releasing three new neutrons and some binding energy.
2. One of those neutrons is absorbed by an atom of uranium-238 and does not continue the reaction. Another neutron is simply lost and does not collide with anything, also not continuing the reaction. However one neutron does collide with an atom of uranium-235, which then fissions and releases two neutrons and some binding energy. 3. Both of those neutrons collide with uranium-235 atoms, each of which fissions and releases between one and three neutrons, which can then continue the reaction.



20. With Leo Szilard at Saranac Lake, September 1945, reenacting the signing of the August 1939 letter to President Roosevelt urging support of nuclear research. The reenactment was for the weekly newsreel series, the March of Time.



Einstein–Szilárd letter



Robert Oppenheimer circa 1944
1904-1967

Leslie Richard Groves

1896– 1970

Manhattan Project

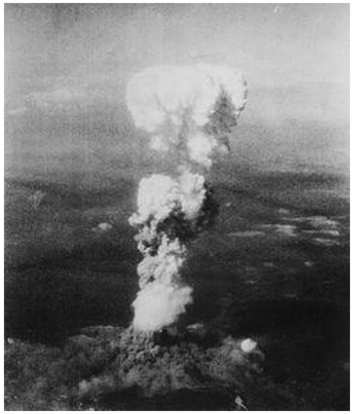
The Manhattan Project created the first nuclear bombs. The first human-engineered nuclear detonation, the Trinity test, is shown.

美國政府成立了一個臨時委員會來考慮是否該用上原子彈。委員會主席是戰爭部長史汀生，成員包括哈佛大學校長、麻省理工學院校長、海軍次長、科學研究辦公室主任等人。這委員會指派了一個科學顧問組提供諮詢，四位成員是歐本海默、費米、勞倫斯、康普頓；這四個人除了歐本海默之外，都是諾貝爾物理獎得主。臨時委員會最終建議杜魯門總統「應該盡快用原子彈對付日本」。

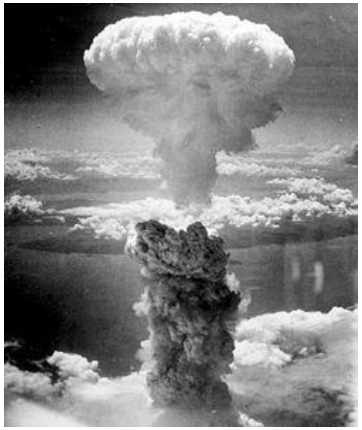
Harry Truman

1884-1972

33rd President of the United States



The mushroom cloud over Hiroshima after the dropping of Little Boy

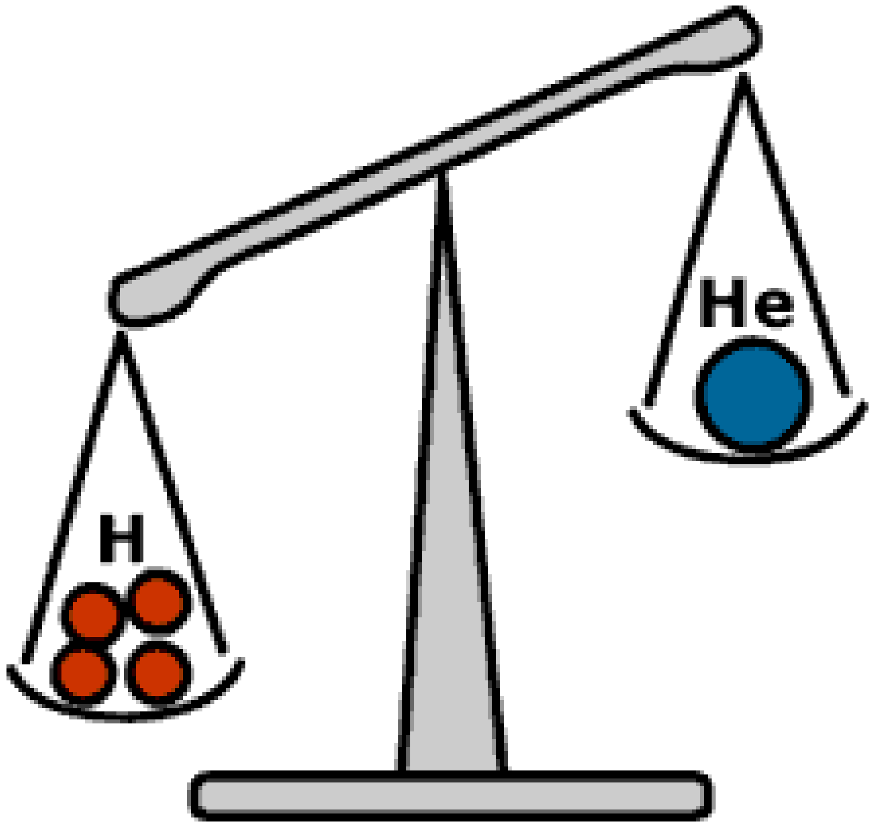


The nuclear explosion over Nagasaki

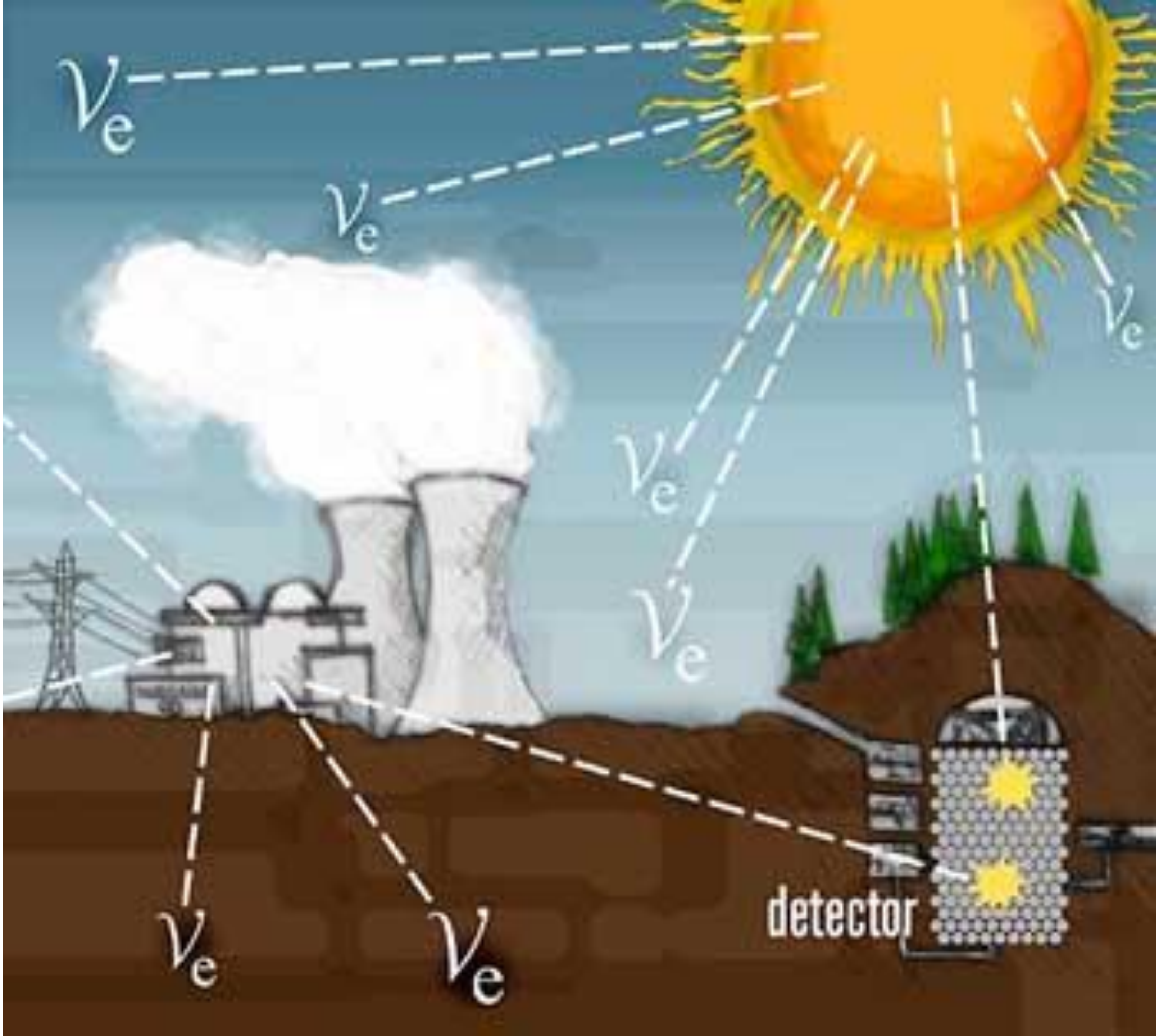
約 9 萬人死亡

約 4 萬人死亡

鼓動愛因斯坦上書羅斯福總統重視原子能研究的齊拉德(Szilard)就取得了數十位科學家的連署，呼籲杜魯門千萬要慎重。這些人準備了一份報告反對臨時委員會的建議，他們認為「不預警地對日本使用核子武器是不恰當的」。

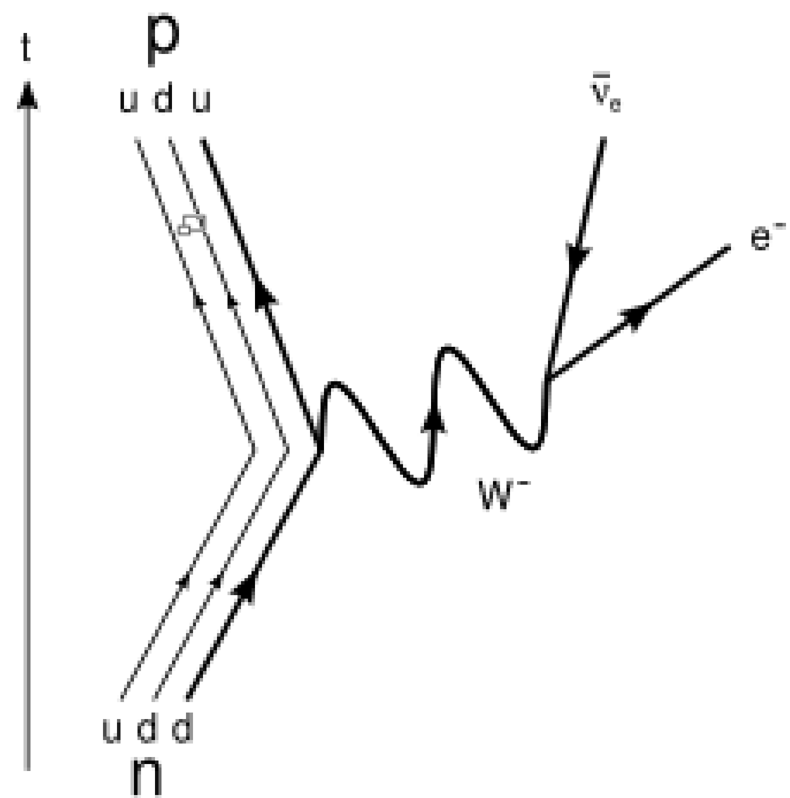


Aston showed in 1920 that four hydrogen nuclei are heavier than a helium nucleus

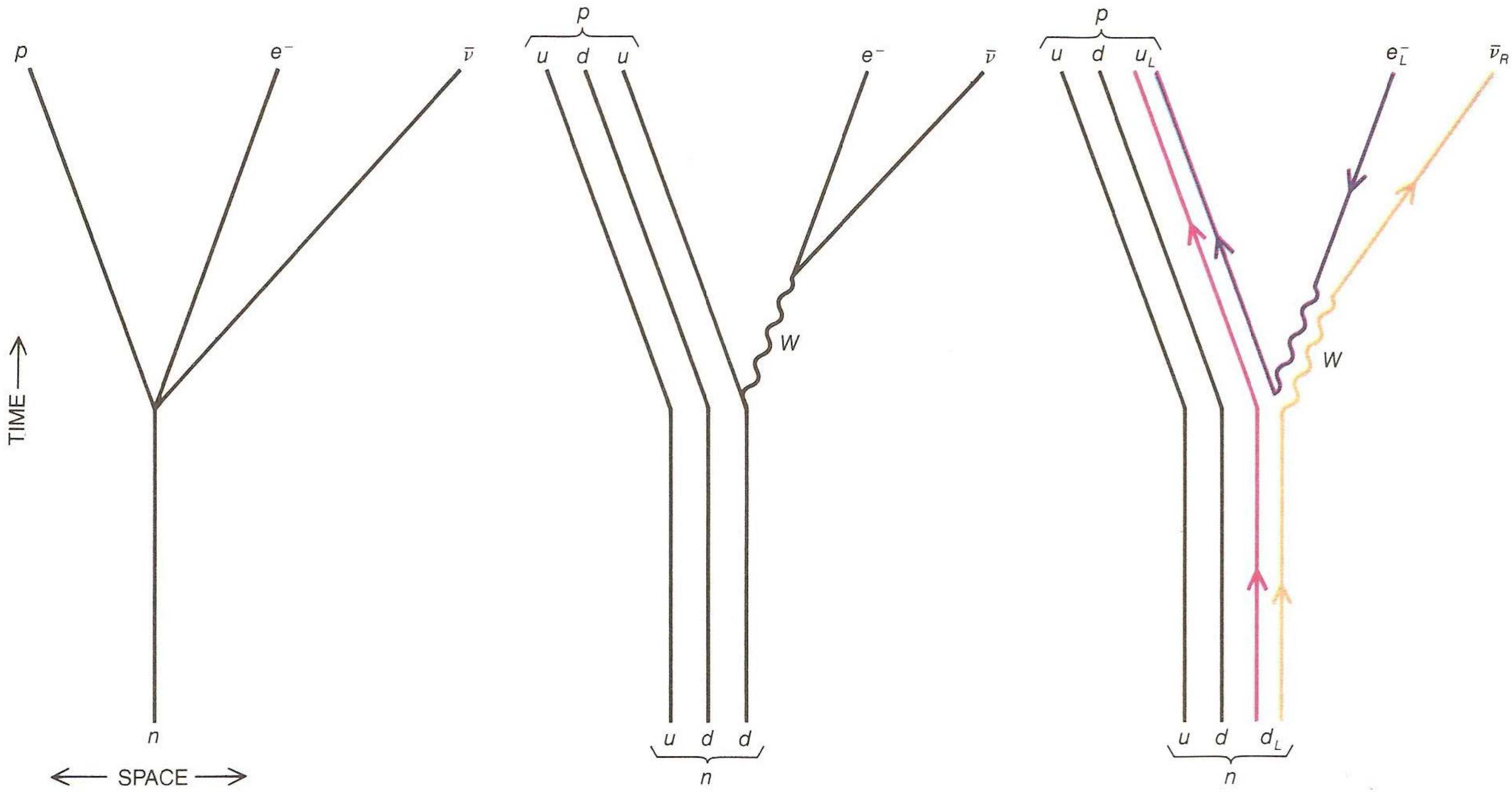

ν_e
ν_e
ν_e
ν_e
ν_e
ν_e
ν_e
detector

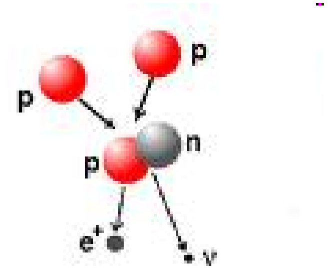
n → p + e + v

中子β衰變　　β decay



弱交互作用

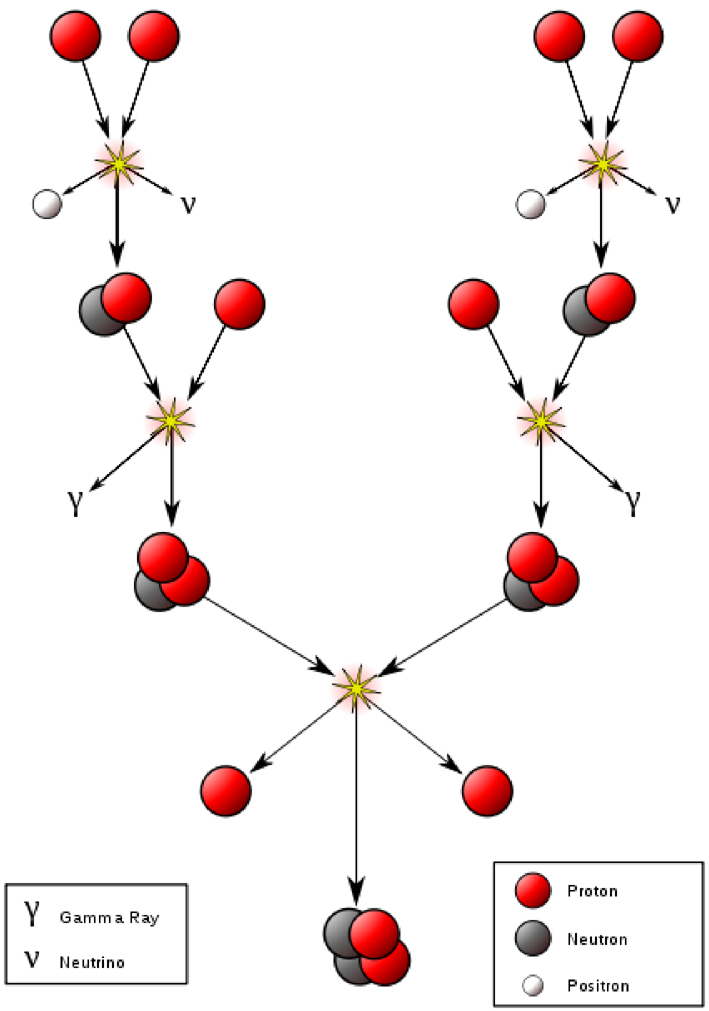




$^{1}_{1}H$ + $^{1}_{1}H$ → $^{2}_{1}D$ + e+ + νe + 0.42 MeV

e^{-} + e+ → 2 γ + 1.02 MeV

$^{2}_{1}D$ + $^{1}_{1}H$ → $^{3}_{2}He$ + γ + 5.49 MeV



The pp I branch

$^{3}_{2}He$ + $^{3}_{2}He$ → $^{4}_{2}He$ + 2 $^{1}_{1}H$ + 12.86 M
eV

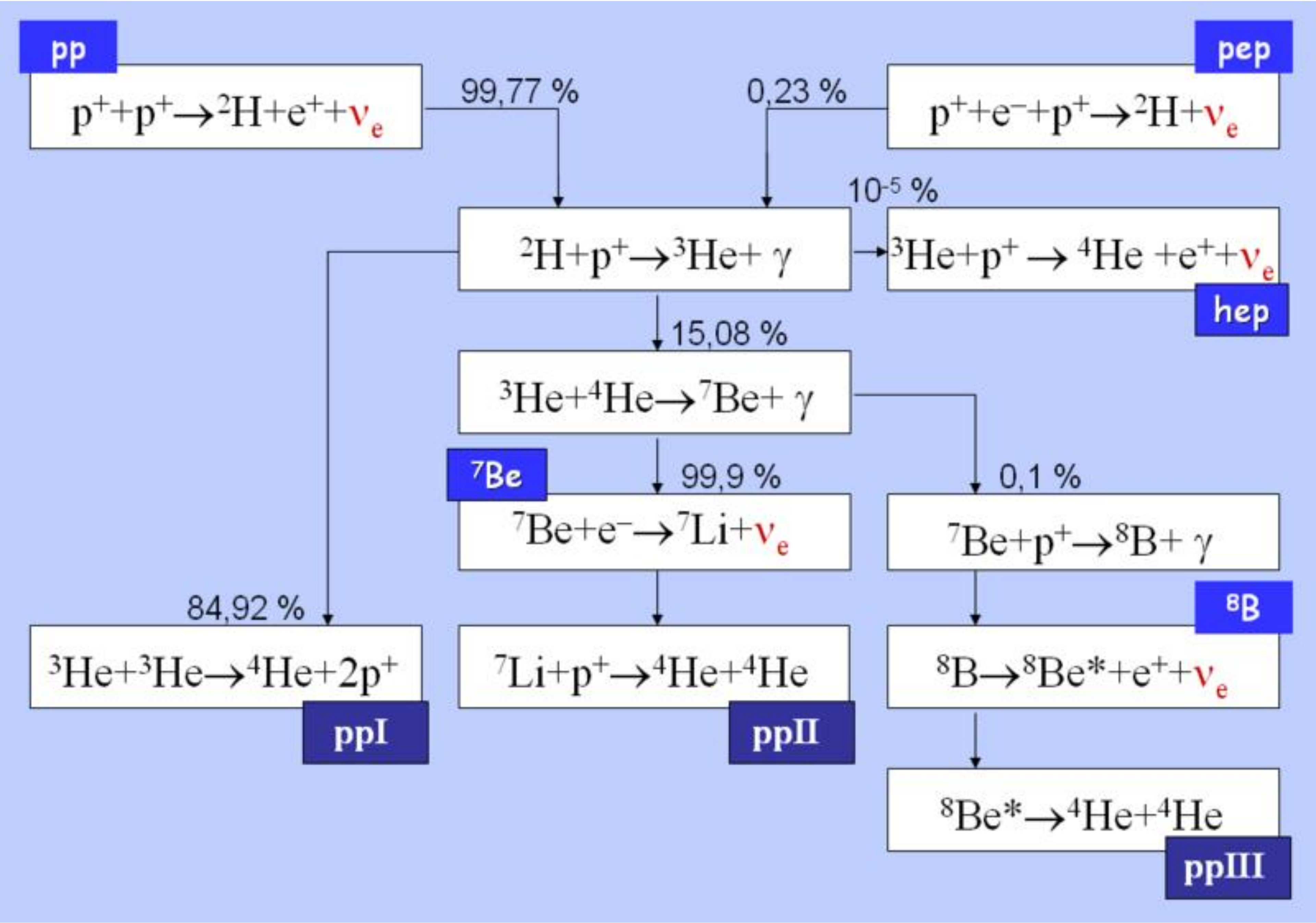
In reaction 1, two hydrogen nuclei (1H, protons) are fused to produce a heavy hydrogen nucleus (2H, a deuteron). This is the usual way nuclear burning gets started in the sun. On rare occasions, the process is started by reaction 2. Deuterons produced in reactions 1 and 2 fuse with protons to produce a light element of helium (3He). At this point, the p—p chain breaks into three branches, whose relative frequencies are indicated in the figure. **The net result of this chain is the fusion of four protons into a single ordinary helium nucleus (4He) with energy being released to the star in accordance with Einstein's equation**. Particles called 'neutrinos' ( ) are emitted in these fusion processes. Their energies are shown in the figure in units of millions of electron volts (MeV). Reactions 2 and 4 were not discussed by Hans Bethe.

Energy release

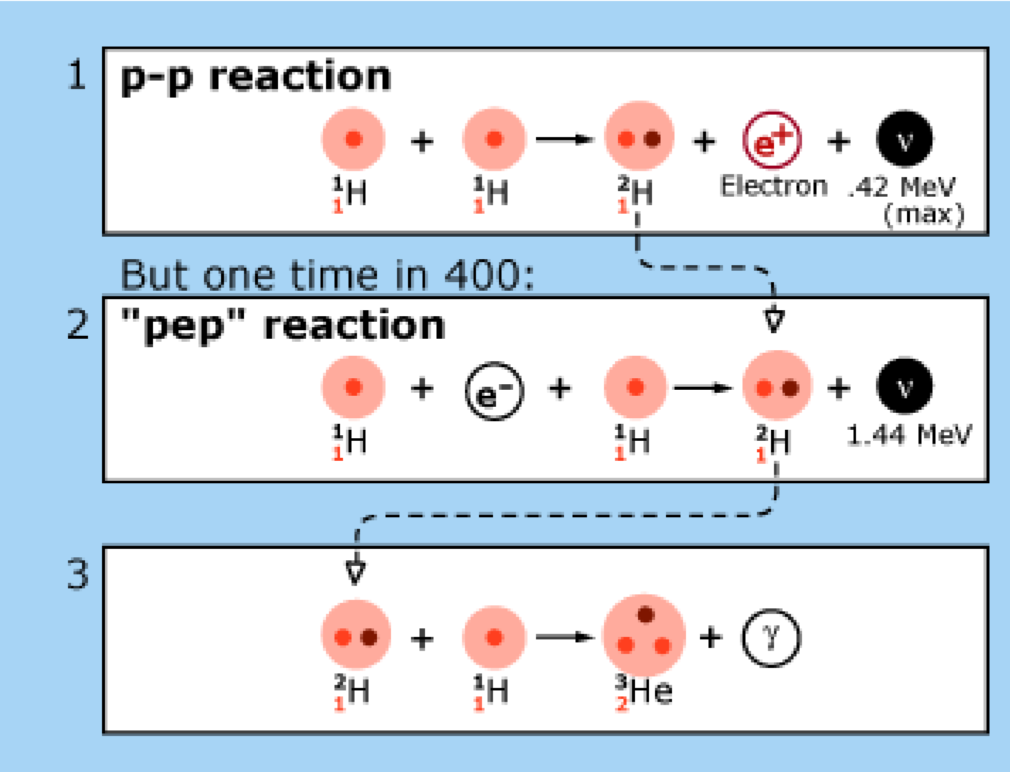
Comparing the mass of the final helium-4 atom with the masses of the four protons reveals that **0.007 or 0.7% of the mass of the original protons has been lost**. This mass has been converted into energy, in the form of gamma rays and neutrinos released during each of the individual reactions. The total energy we get in one whole chain is 26.73 MeV.

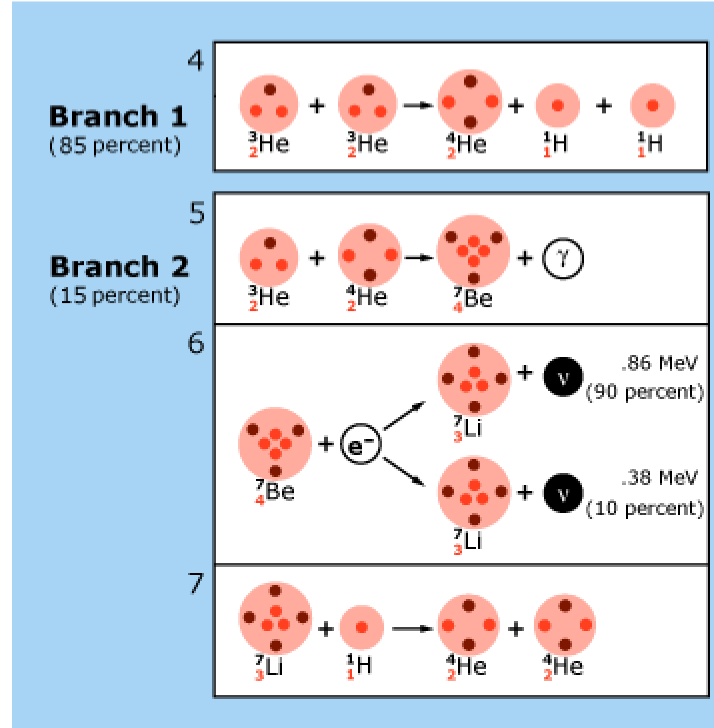
Only energy released as gamma rays will interact with electrons and protons and heat the interior of the Sun. This heating supports the Sun and prevents it from collapsing under its own weight.

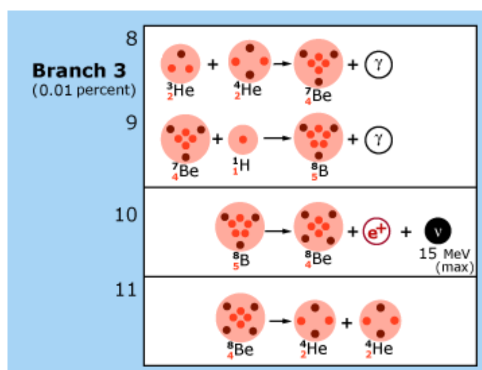
Neutrinos do not interact significantly with matter and do not help support the Sun against gravitational collapse. The neutrinos in the ppI, ppII and ppIII chains carry away 2.0%, 4.0% and 28.3% of the energy in those reactions respectively.

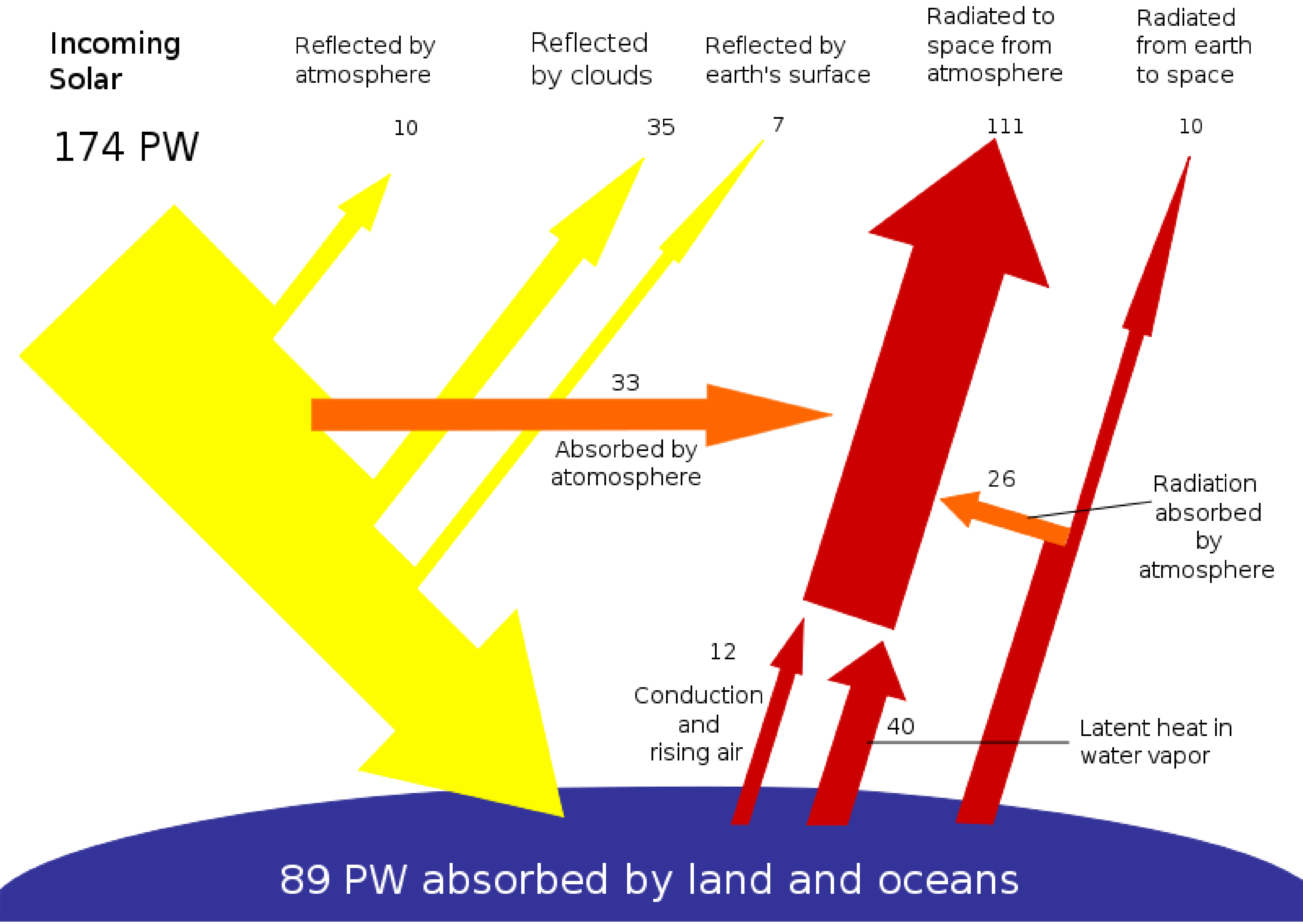


pp
$p^+ + p^+ \rightarrow {}^2H + e^+ + \nu_e$
99,77 %
0,23 %
pep
$p^+ + e^- + p^+ \rightarrow {}^2H + \nu_e$
10-5 %
${}^2H + p^+ \rightarrow {}^3He + \gamma$
${}^3He + p^+ \rightarrow {}^4He + e^+ + \nu_e$
hep
15,08 %
${}^3He + {}^4He \rightarrow {}^7Be + \gamma$
7Be
99,9 %
0,1 %
${}^7Be + e^- \rightarrow {}^7Li + \nu_e$
${}^7Be + p^+ \rightarrow {}^8B + \gamma$
84,92 %
8B
${}^3He + {}^3He \rightarrow {}^4He + 2p^+$
${}^7Li + p^+ \rightarrow {}^4He + {}^4He$
${}^8B \rightarrow {}^8Be^* + e^+ + \nu_e$
ppI
ppII
${}^8Be^* \rightarrow {}^4He + {}^4He$
ppIII

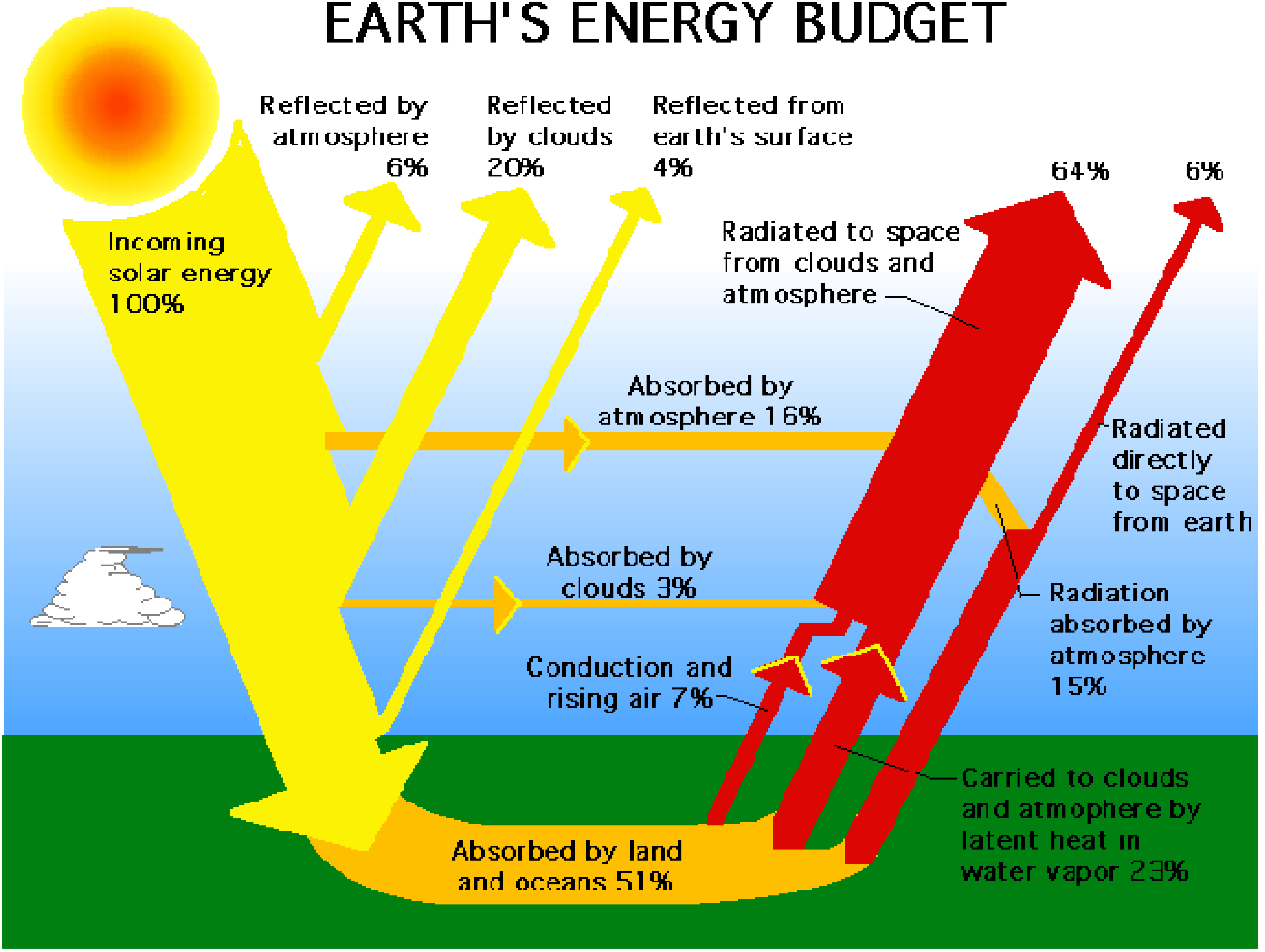

1
p-p reaction
^1_1H + ^1_1H → ^2_1H + e^+ + ν
Electron
.42 MeV (max)
But one time in 400:
2
"pep" reaction
^1_1H + e^- + ^1_1H → ^2_1H + ν
1.44 MeV
3
^2_1H + ^1_1H → ^3_2He + γ


4
Branch 1
(85 percent)
^3_2He + ^3_2He → ^4_2He + ^1_1H + ^1_1H
5
Branch 2
(15 percent)
^3_2He + ^4_2He → ^7_4Be + γ
6
^7_4Be + e^-
^7_3Li + ν .86 MeV (90 percent)
^7_3Li + ν .38 MeV (10 percent)
7
^7_3Li + ^1_1H → ^4_2He + ^4_2He


8
Branch 3
(0.01 percent)
^3_2He + ^4_2He → ^7_4Be + γ
9
^7_4Be + ^1_1H → ^8_5B + γ
10
^8_5B → ^8_4Be + e^+ + ν
15 MeV (max)
11
^8_4Be → ^4_2He + ^4_2He

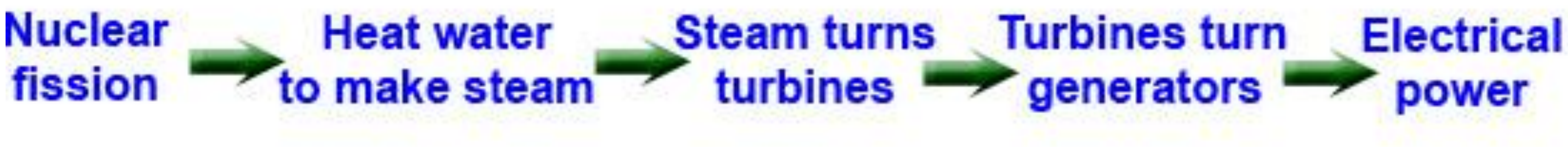

Incoming Solar
174 PW
Reflected by atmosphere
10
Reflected by clouds
35
Reflected by earth's surface
7
Radiated to space from atmosphere
111
Radiated from earth to space
10
33
Absorbed by atomosphere
26
Radiation absorbed by atmosphere
12
Conduction and rising air
40
Latent heat in water vapor
89 PW absorbed by land and oceans

EARTH'S ENERGY BUDGET



Nuclear Power

The main bit to remember:



http://www.darvill.clara.net/altenerg/nuclear.htm