

Лятна учителска школа 02-06.07.2018

Физика на микросвета

**Естествена и изкуствена
радиоактивност. Откриване. Видове
лъчения. Таблица на изотопите.**

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Какъв е произхода на химичните елементите

Periodic Table of the Elements

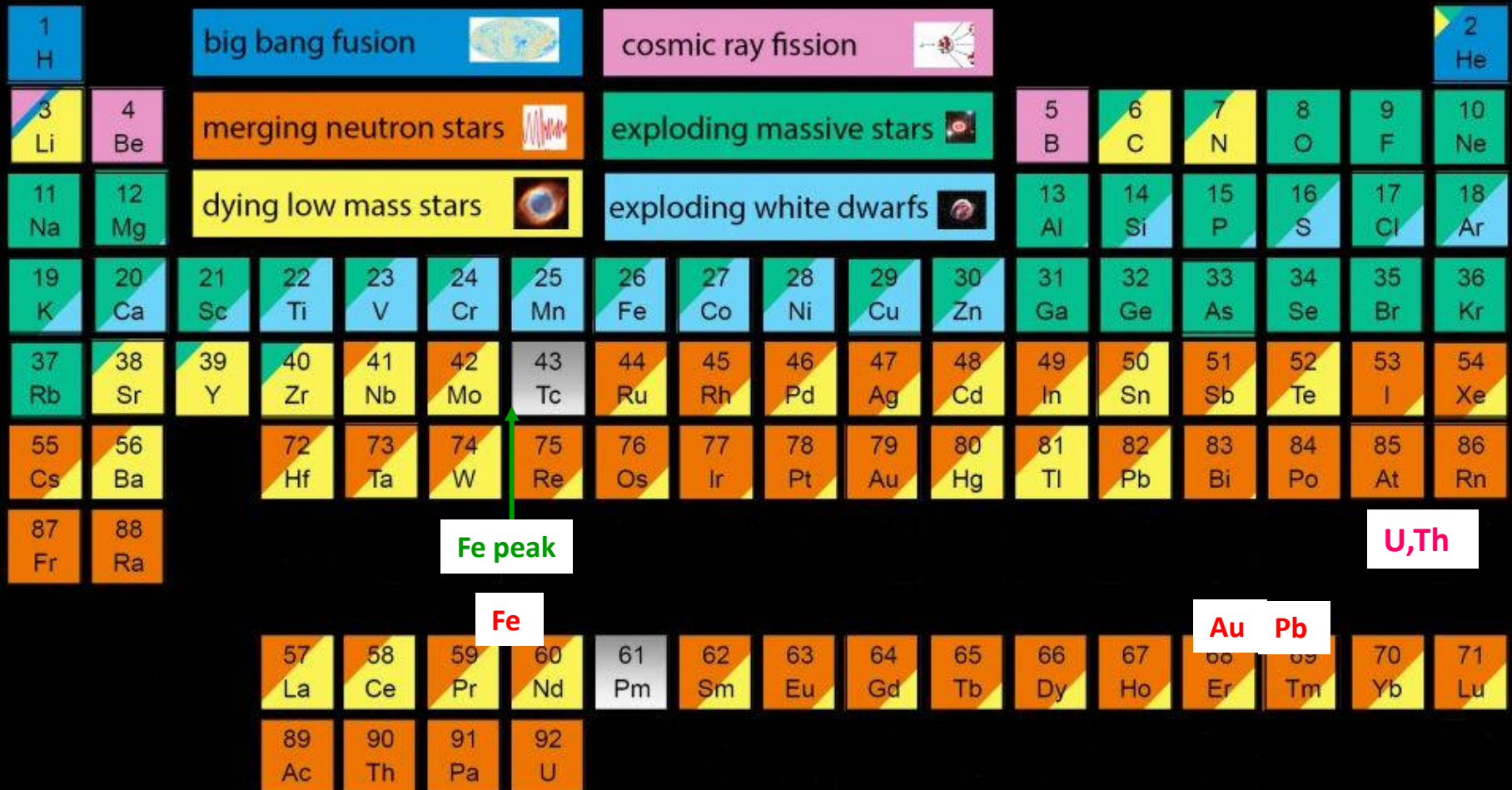
1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.972	35 Br Bromine 79.904	36 Kr Krypton 84.798
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.384	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [209]	85 At Astatine [209]	86 Rn Radon [222]
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Nh Nihonium unknown	114 Fl Flerovium [289]	115 Mc Moscovium unknown	116 Lv Livermorium [293]	117 Ts Tennessine unknown	118 Og Oganesson unknown
57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.242	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967			
89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]			

Legend:

- Alkali Metal
- Alkaline Earth
- Transition Metal
- Basic Metal
- Semimetal
- Nonmetal
- Halogen
- Noble Gas
- Lanthanide
- Actinide

Какъв е произхода на химичните елементи

The Origin of the Solar System Elements



По важни събития от историята на ядрената физика

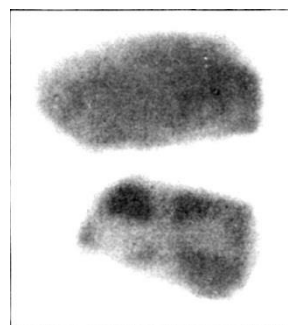
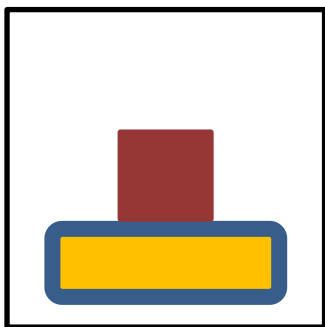
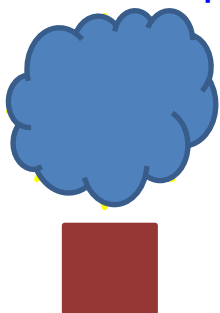
- 1896 – Becquerel – открива радиоактивността;

Има ли флуоресциращи материали, които излъчват X – лъчи?

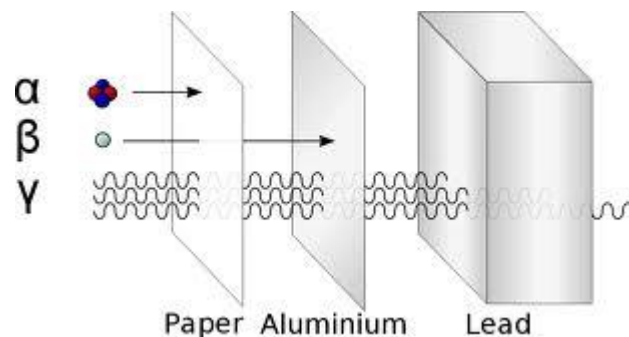
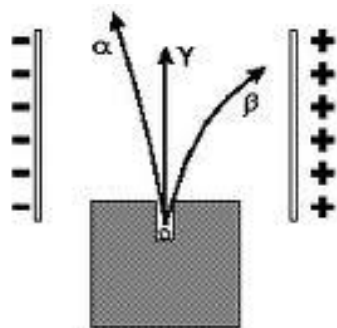
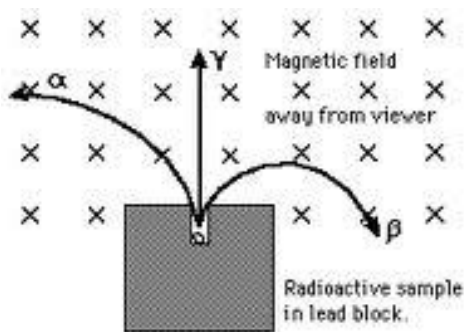


Систематични измервания!

Нов тип лъчение
спонтанна радиация



S.P. Thompson, Lord Kelvin



- 1898 – Marie and Pierre Curie – термина радиоактивност и изолират Ra и Po;

По важни събития от историята на ядрената физика

- 1911 – Rutherford – открива атомното ядро

- 1917 – Rutherford, Mardsen протона;



- 1919 – Rutherford – открива ядрените превръщания при ядрени реакции;

- 1919 – Aston – разработва първия мас спектрометър;

- 1925 – Goudsmit, Uhlenbeck – собствен спин;

- 1928 – Gamov, Gurney, Condon – теория на α - разпада;

- 1930 – Pauli – неутринна хипотеза;

- 1931 – Van de Graaff – първи електростатичен ускорител;

- 1931 – Sloan, Lawrence – първи линеен ускорител;

- 1932 – Lawrence, Livingston – първи циклотрон;

- 1932 – Anderson – открива позитрона;

По важни събития от историята на ядрената физика

- 1932 – Chadwick – открива нейтрона;



- 1932 – Cockcroft, Walton – ядрени реакции, чрез използване на ускорител;



- 1934 – I. Curie, F. Joliot – откриват изкуствената радиоактивност;



- 1934 – E. Fermi – теория на β -разпада;
- 1935 – Yukawa – мезонна хипотеза;
- 1935 – Bothe – предлага техниката на съвпадение;
- 1936 – N. Bohr – теория на съставното ядро;

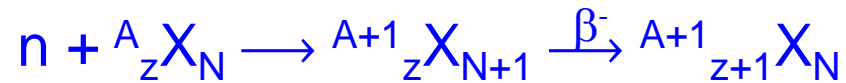
По важни събития от историята на ядрената физика

- 1938/39 – Hahn, Strassmann/ Meitner and Frisch – откриват ядреното делене;

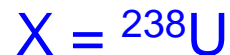
1930 – откриване на неутрона – Chadwick (N.P. 1932)

Какво се случва когато се облъчат ядра с неутрони?

1934 - 6 – захват на неутрон + β -разпад – Fermi (N.P. 1938)



Може ли да синтезираме елемент с по-голям атомен номер от 92?



1939 – получения елемент е Ba (Z=56) – Hahn&Strassmann

По важни събития от историята на ядрената физика

- 1938 – Bethe – ядреното сливане е енергетичния източник на звездите;
- 1939 – Borh, Wheeler – първи модел описващ ядреното делене;
- 1940 – McMillan, Seaborg – получават първия изкуствено създаден елемент;
- 1942 – E. Fermi – първи ядрен реактор;
- 1945 – първа ядрена бомба;
- 1946 – Gamow – Big Bang космология;
- 1946 – Bloch, Purcell – ядрено-магнитен резонанс;
- 1947 – Libby – радиоактивно датирание;
- 1949 – Mayer, Jensen, Haxel, Suess – слоест модел на атомното ядро;
- 1952 – първа термоядрена бомба;
- 1953 – A. Borh, B. Mottelson – колективен модел на атомното ядро;
- 1955 – Nilsson – деформиран слоест модел;

Ядрена физика

Nuclear Science

Nuclear Science is the study of the structure, properties, and interactions of the atomic nucleus. Nuclear scientists calculate and measure the masses, shapes, sizes, and decays of nuclei at rest and in collisions. They ask questions, such as: Why do nuclei stay in the nucleus? What combinations of protons and neutrons are possible? What happens when nuclei are compressed or rapidly rotated? What is the origin of the nuclei found on Earth?

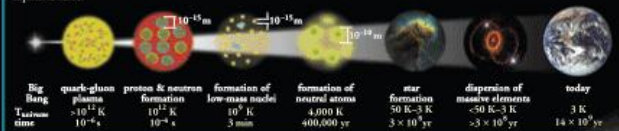
Legend

- Electron (e^-)
- positron (e^+)
- neutrino (ν)
- antineutrino ($\bar{\nu}$)
- quark
- gluon field
- gluon
- photon (γ)

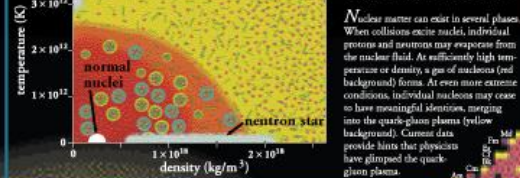
Mass Number = 14
Atomic Number = 6
Neutron Number = A - Z

Expansion of the Universe

After the Big Bang, the universe expanded and cooled. At about 10^{-35} second, the universe consisted of a soup of quarks, gluons, electrons, and neutrinos. When the temperature of the Universe cooled to about 10^9 K, this soup coalesced into protons, neutrons, and electrons. As time progressed, some of the protons and neutrons formed deuterium, helium, and lithium nuclei. Still later, electrons combined with protons and these low-mass nuclei to form neutral atoms. Due to gravity, clouds of atoms contracted into stars, where hydrogen and helium fused into more massive chemical elements. Exploding stars (supernovae) form the most massive elements and disperse them into space. Our earth was formed from supernova debris.

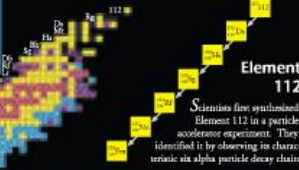


Phases of Nuclear Matter



Unstable Nuclei

Stable nuclei form a narrow white band on the Chart of the Nuclides. Scientists produce unstable nuclei far from this band and study their decays, thereby learning about the extremes of nuclear conditions. In its present form, this chart contains about 2900 different nuclei. Nuclear theory predicts that there are at least 4000 more to be discovered with $Z \leq 112$.



Radioactivity

Radioactive decay transforms a nucleus by emitting different particles in alpha decay, the nucleus releases a ^4He nucleus—an alpha particle. In beta decay, the nucleus either emits an electron and antineutrino (for a positron and neutrino) or captures an atomic electron and emits a neutrino. A positron is the name for the antiparticle of the electron. Antimatter is composed of antiparticles. Both alpha and beta decays change the original nucleus into a nucleus of a different chemical element. In gamma decay, the nucleus lowers its internal energy by emitting a photon—a gamma ray. This decay does not modify the chemical properties of the atom.

Alpha Decay: $^{238}_{92}\text{U} \rightarrow ^{234}_{90}\text{Th} + ^4_2\text{He}$

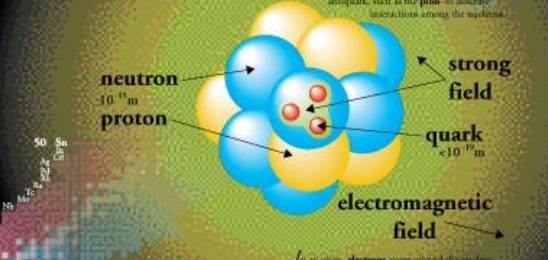
Beta Minus Decay: $^{14}_6\text{C} \rightarrow ^{14}_7\text{N} + e^- + \bar{\nu}_e$

Beta Plus Decay: $^{11}_6\text{C} \rightarrow ^{11}_5\text{B} + e^+ + \nu_e$

Gamma Decay: $^{60}_{27}\text{Co} \rightarrow ^{60}_{27}\text{Co} + \gamma$

The Nucleus

$(1-10) \times 10^{-15}$ m



Nuclear Energy

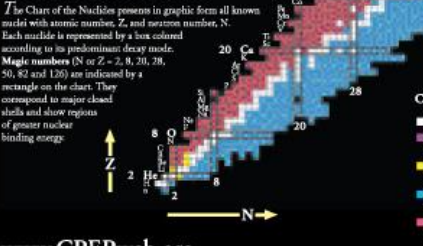
Nuclear reactions release energy when the total mass of the products is less than the sum of the masses of the initial nuclei. The "lost" mass appears as kinetic energy of the products ($E = mc^2$). In fission, a massive nucleus splits into two major fragments that usually eject one or more neutrons. In fusion, low mass nuclei combine to form a more massive nucleus plus one or more ejected particles—neutrons, protons, photons, or alpha particles.

Fission: $^{235}_{92}\text{U} + n \rightarrow ^{141}_{54}\text{Xe} + ^{92}_{38}\text{Sr} + 2n$

Fusion: $^2_1\text{H} + ^3_1\text{H} \rightarrow ^4_2\text{He} + n$

In the early stages of stellar evolution of our sun and other stars, hydrogen fuses to form helium, releasing energy in the form of photons (light) and neutrinos. During the later stages of stellar evolution, more massive nuclei up to and beyond uranium are synthesized by fusion. By measuring the number of neutrinos that come from the Sun, scientists recently have demonstrated that neutrino must have a mass greater than zero.

Chart of the Nuclides



www.CPEPweb.org

Applications

Radioactive Dating: Naturally occurring radioactive isotopes such as ^{14}C are used to date objects that were once living, such as wood. For example, from a study of artifacts found at the site, scientists determined that Stonehenge was built nearly 4,000 years ago.

Smoke Detectors: Many smoke detectors use a small amount of the alpha emitting ^{241}Am to ionize the air. Smoke entering the detector reduces the current and sets off the alarm.

Nuclear Medicine: Radioactive isotopes, such as ^{67}Ga , ^{67}Cu and ^{125}I , are commonly used in the diagnosis and treatment of disease. Positron emitting radiotracers such as ^{18}F are used in Positron Emission Tomography (PET) to generate images of brain activity.

Space Exploration: Scientists used alpha particles to identify chemical elements present in Martian rocks. On Earth, nuclear isotopes are used in many other nuclear applications generate radiometric dating tracers of this nature is a subject of intense research.

Nuclear Reactors: Alpha particles are the fission of ^{235}U or ^{239}Pu nuclei to produce electric power. Reactors and other nuclear applications generate radiometric dating tracers of this nature is a subject of intense research.

Magnetic Resonance Imaging: Magnetic Resonance Imaging (MRI) makes use of magnetic conditions involving the magnetic field of a nucleus to study the local chemical environment. This technique accurately maps the density of hydrogen to produce three-dimensional images of the human body.

Основни величини и задачи в ядрената физика

- Енергия – маса на ядрата, енергия на възбудени ядрени състояния;
- Пространствено разпределение на ядрената материя – ядрени радиуси, моменти и ориентация;
- Вероятности – за разпад (времена живот \leftrightarrow закон за радиоактивното разпадане) или реакции (сечения за реакции);

Права (фундаментална) задача

На базата на експериментално изследване на ядрени лъчения се определят характеристики на ядрени състояния:

- Ядрени модели – ядрен много-частичен проблем и ядрена структура;
- Параметри за астрофизични и космологични модели;

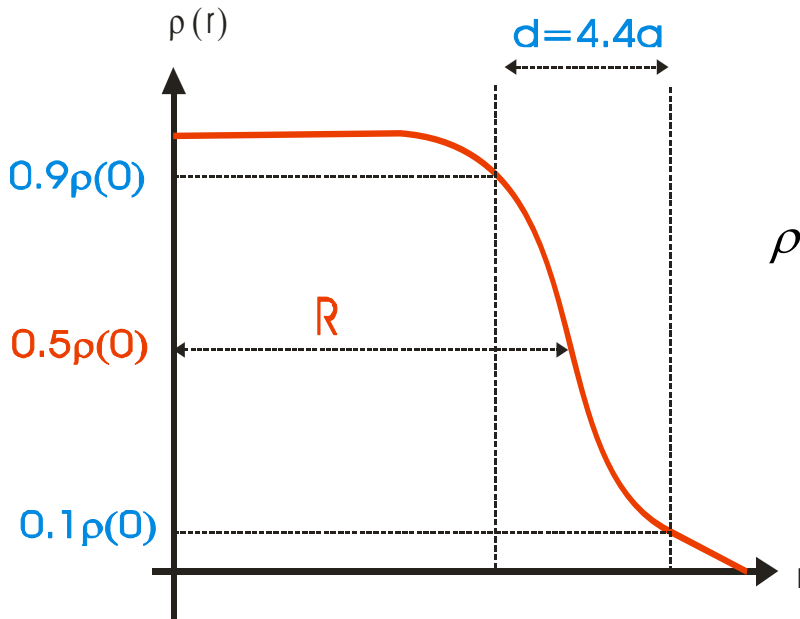
Обратна (приложна) задача

На базата на известни ядрени характеристики да се използват ядрените лъчения и реакции:

- Радиоекология;
- Ядрена енергетика – реактори и батерии;
- Датиране;
- Нуклеарна медицина – диагностика и терапия;
-

Единици в ядрената физика - разстояния

Функция на Ферми

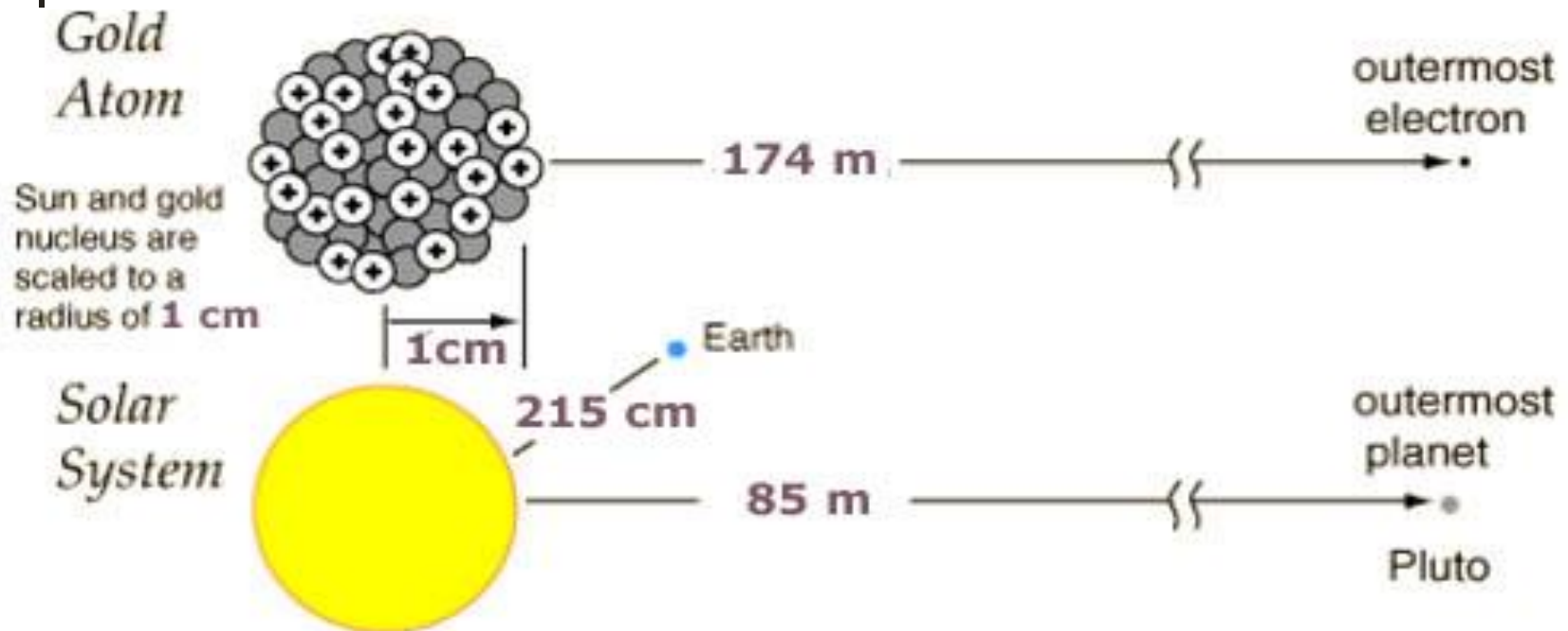


$$\rho(r = R) = 0.5 \rho_0$$

$$\frac{A}{(4/3)\pi R^3} \sim \text{const} \Rightarrow R = \text{const} \cdot A^{1/3}$$

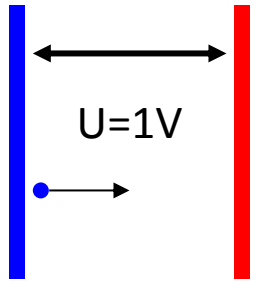
$$R = 1.23(2) A^{1/3} (\text{fm})$$

$$1 \text{ fm} = 10^{-15} \text{ m}$$



Единици в ядрената физика - енергия

$$1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$$



$$E = eU$$

Типичните енергии за γ и β разпади са $\sim 1 \text{ MeV}$, за $\alpha \sim 5-6 \text{ MeV}$

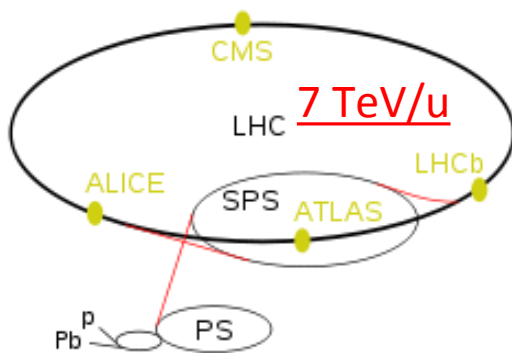
100 W електрическа крушка, за 1 час ще отдели:

$$E = P.t = 100 \text{ W} \cdot 3.6 \times 10^4 \text{ s} = 3.6 \times 10^5 \text{ J} = (3.6 \times 10^5 \text{ J}) / (1.602 \times 10^{-19} \text{ J/eV}) = 2.25 \times 10^{24} \text{ eV} = 2.25 \text{ YeV}$$

- Температурен еквивалент

$$\frac{1 \text{ eV}}{k_B} = \frac{1.60217653(14)10^{-19} \text{ J}}{1.3806505(24)10^{-23} \text{ J/K}} = 11604.505(20) \text{ K} \propto 10^4 \text{ K}$$

Large Hadron Collider
протони до 7 TeV



Мравка тежаща 1 g се движи със скорост 5 cm/s

$$E = \frac{m v^2}{2} = \frac{(10^{-3} \text{ kg}) (5 \times 10^{-2} \text{ m / s})^2}{2} = 1.25 \times 10^{-6} \text{ J}$$

$$= \frac{1.25 \times 10^{-6} \text{ J}}{1.602 \times 10^{-19} \text{ J / eV}} = 0.78 \times 10^{13} \text{ eV} = 7.8 \text{ TeV}$$

Колко нуклеона има в една мравка (от C)?

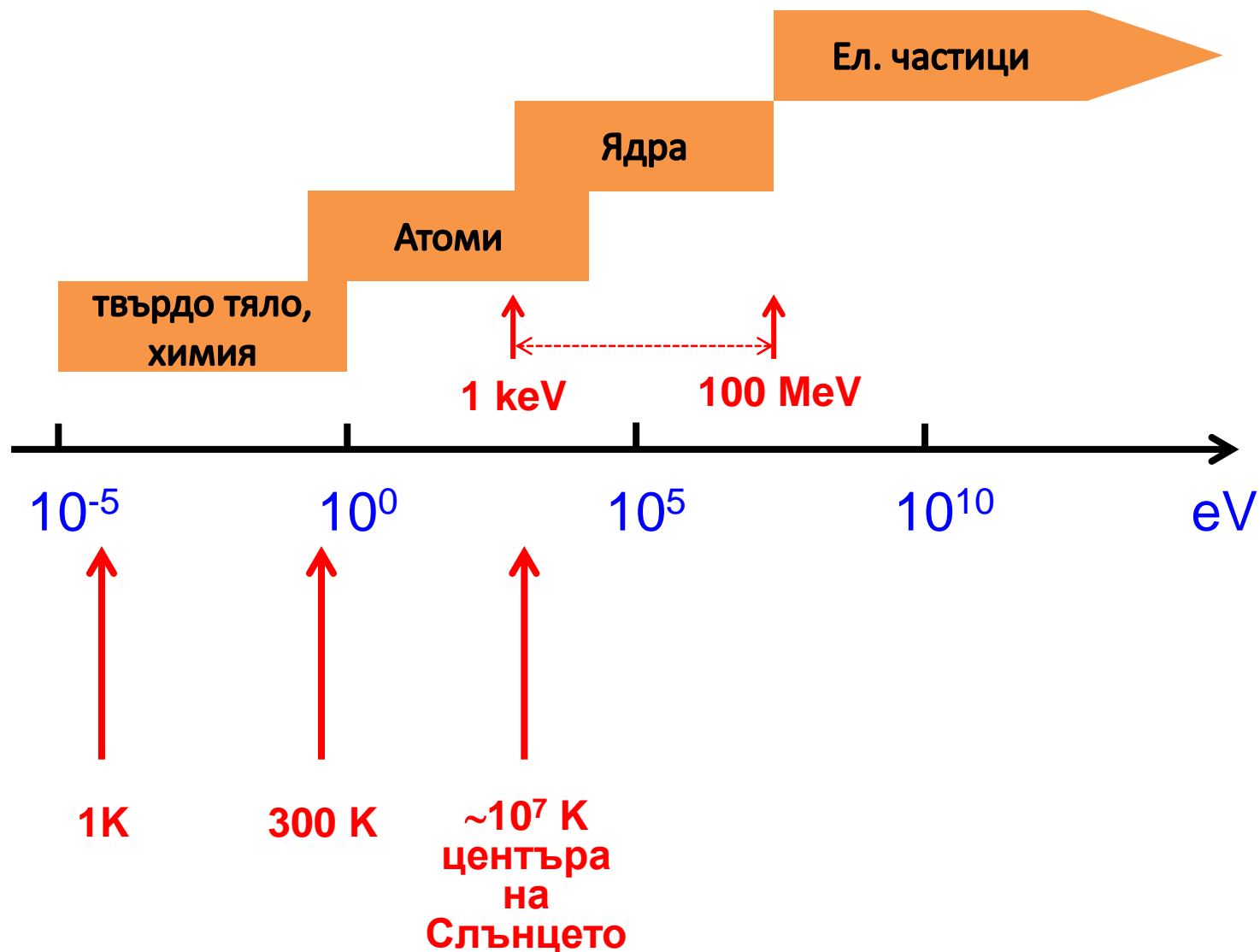
$$\# (\text{C}) = \frac{1 \text{ g}}{12} 6.022 \times 10^{23} \text{ mol / g} = 5 \times 10^{22}$$

$$E / \text{нук} = 1.6 \times 10^{-9} \text{ eV / u}$$

$$\# (\text{p}) + \# (\text{n}) = (6 + 6) \times \# (\text{C}) = 5 \times 10^{23} \text{ u}$$

$$N_A = 6.022 \times 10^{23} \text{ mol / g}$$

Физика на микросвета – разделение по енергии



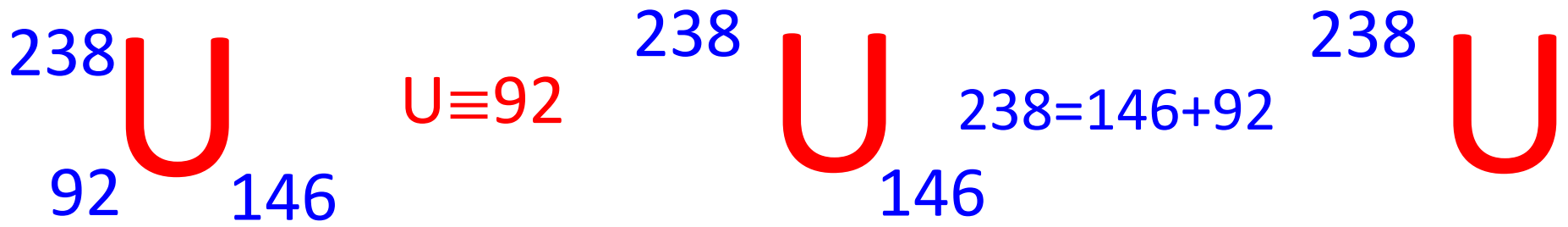
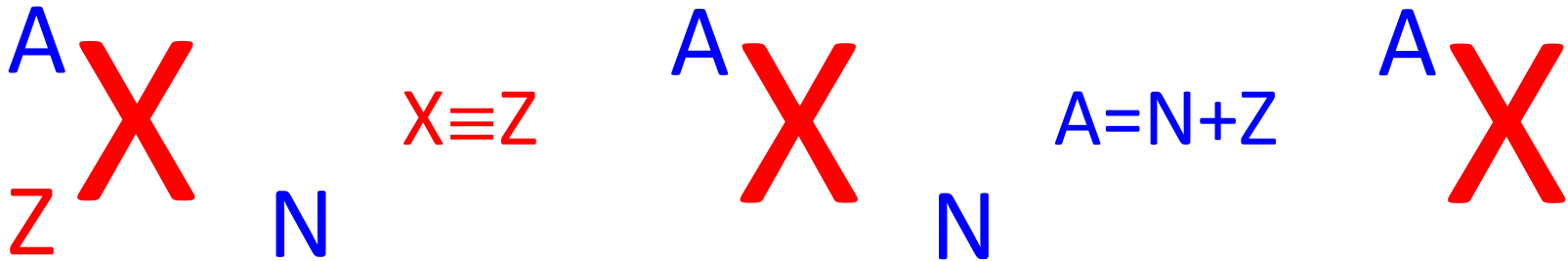
Основни означения

1932 - Chadwick – открива неутрона – **електрически неутрална частица** с маса

$$m_n \approx m_p \quad (m_p = 938.272 \text{ MeV}, m_n = 939.566 \text{ MeV}, \Delta m = 1.293 \text{ MeV})$$

{**протон**, **неутрон**} \equiv **нуклеон**

ЯДРО \equiv Z, N, A=N+Z



Z – константа – **ИЗОТОПИ** (^{112}Sn , ^{114}Sn , ^{115}Sn , ^{116}Sn , ^{118}Sn , ^{120}Sn)

N – константа – **ИЗОТОНИ** (^{132}Te , ^{134}Xe , ^{136}Ba , ^{138}Ce)

Ядрена маса и енергия на свързване

$$m(N, Z)c^2 = m_{\text{атом}}c^2 - Zm_e c^2 + \sum_{i=1}^Z B_i^e$$

$$B_i^e \approx 10 - 100 \text{ keV}$$
$$m(N, Z) = A \cdot 1000 \text{ MeV}$$

10^{-6}

$$B(N, Z) = (Zm_p + Nm_n - (m_{\text{атом}} - Zm_e))c^2$$

$$B(N, Z) = (Z({}^1\text{H}) + Nm_n - m_{\text{атом}})c^2$$

По дефиниция: $1 \text{ u (amu)} = 1/12 M({}^{12}\text{C})$ или $M({}^{12}\text{C}) = 12 \text{ u}$

$$1 \text{ u} = 1.6605 \cdot 10^{-24} \text{ g}$$
$$c^2 = 931.494 \text{ MeV/u}$$

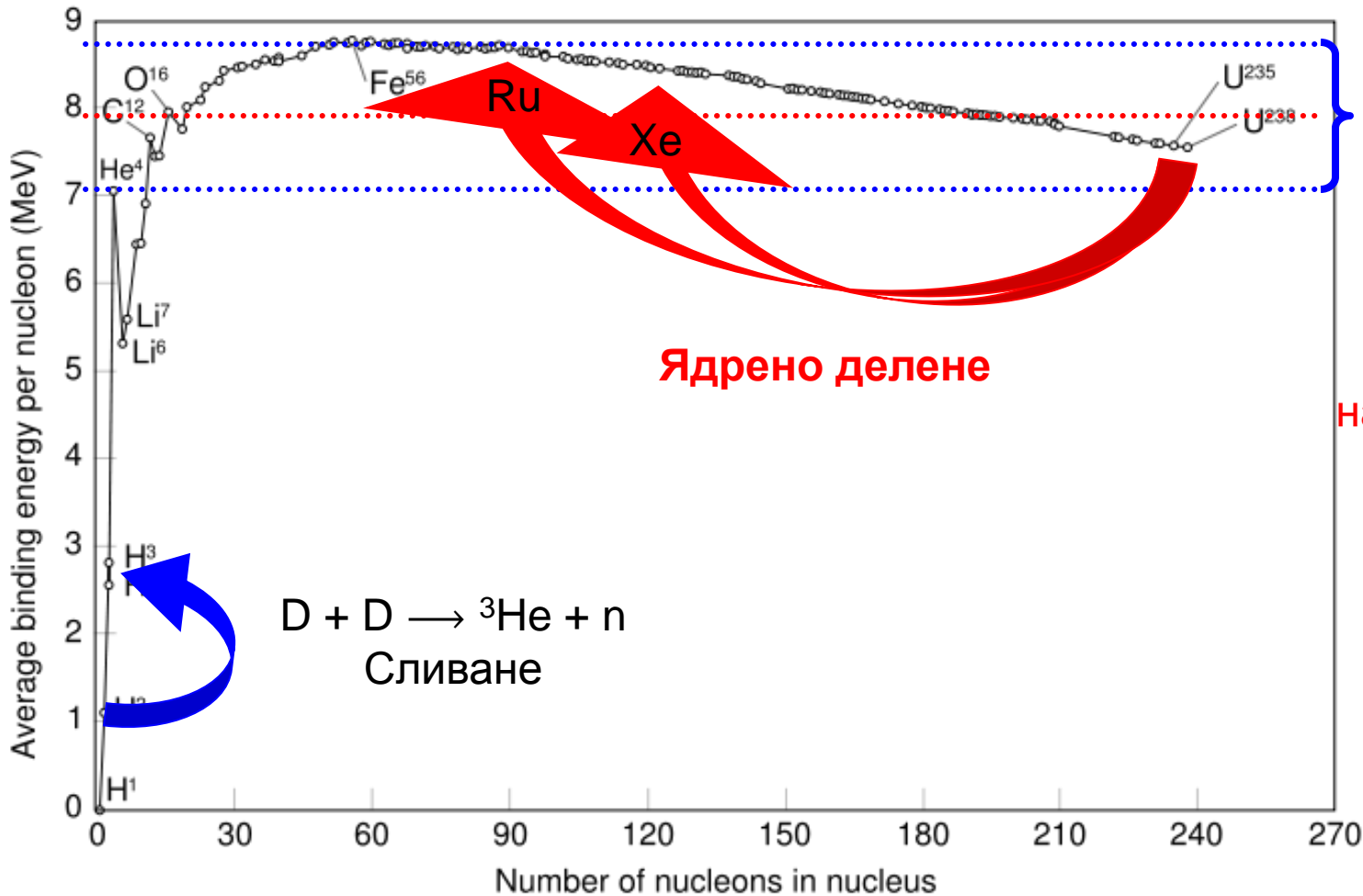
$$m_p = 1.00782503207(10) \text{ u}$$
$$m_n = 1.0086649157(6) \text{ u}$$

Енергия на свързване

$$m({}_Z^A X_N) = [Zm({}^1\text{H}) + Nm_n - \frac{1}{c^2} B(N, Z)]$$

$$\Delta = (m({}_Z^A X_N) - A)c^2$$

Енергетичния остатък/излишък от образуването на ядрена свързана система



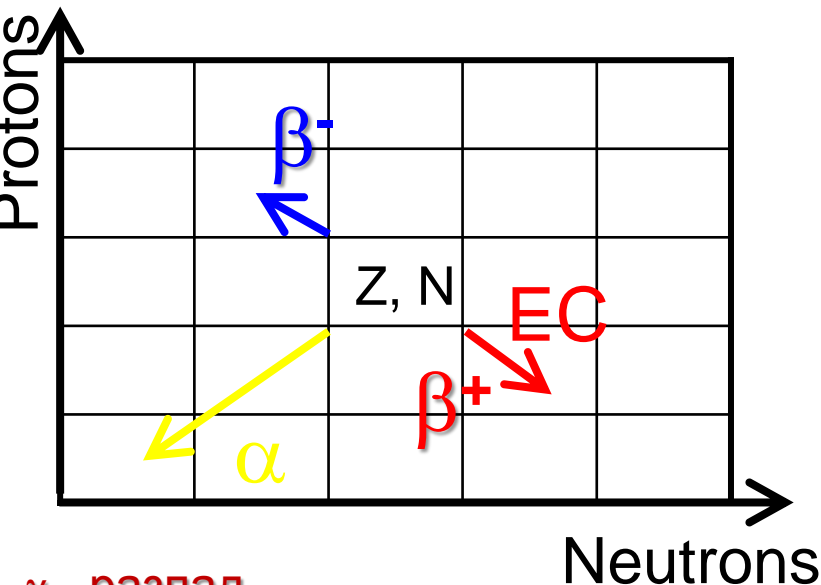
$$B/A \sim \text{const} = 8.0(8) \text{ MeV}$$

~~$$B \sim A(A-1)$$~~

$$B \sim A$$

най-близки съседи

Ядрени разпади



α-разпад:

- излъчване на ${}^4\text{He}$ ядра
- $Z \rightarrow Z-2$ $N \rightarrow N-2$
- $A \rightarrow A-4$

β⁻ - разпад:

- излъчване на e^- и $\bar{\nu}$
- $Z \rightarrow Z+1$ $N \rightarrow N-1$
- $A = \text{const}$

β⁺ - разпад:

- излъчване на e^+ и ν
- $Z \rightarrow Z-1$ $N \rightarrow N+1$
- $A = \text{const}$

γ - разпад

- $Z, N, A = \text{const}$

Редки разпад

- n или p ;
- ${}^8\text{Be}$, ${}^{12}\text{C}$, ${}^{16}\text{O}$

Спонтанно делене

- $A > 230$
- ${}^AX \rightarrow {}^{A1}Y + {}^{A2}Z + \#n$

Електронен захват (EC)

- Поглъщане на e^- и излъчване на ν
- $Z \rightarrow Z-1$ $N \rightarrow N+1$
- $A = \text{const}$

Вероятност за разпад за единица време на ядро

$$\lambda = -\frac{dN / dt}{N}$$

$$\tau = \int_0^{\infty} t \lambda e^{-\lambda t} dt = \frac{1}{\lambda}$$

$$T_{1/2} = \frac{\ln 2}{\lambda}$$

$$\lambda = \frac{2\pi}{\hbar} \rho(E_n) |V_{nl}|^2$$

$$V_{fi} = \int \psi_f^* \hat{V} \psi_i d\nu$$

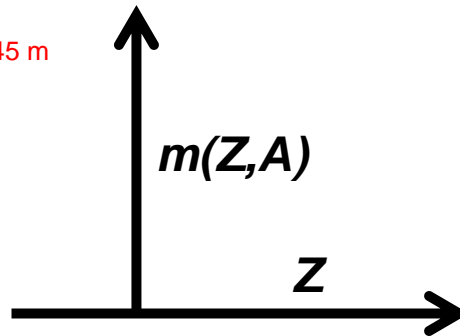
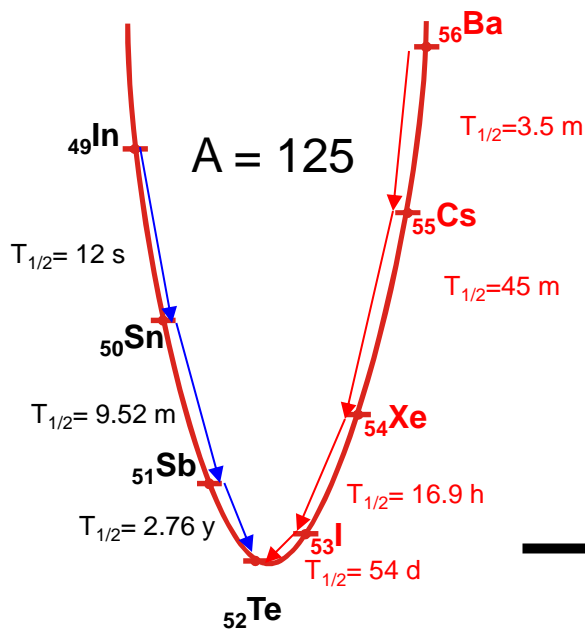
Линия на стабилност

$$m(Z, A) = Zm({}^1\text{H}) + Nm_n - B(Z, A) / c^2$$

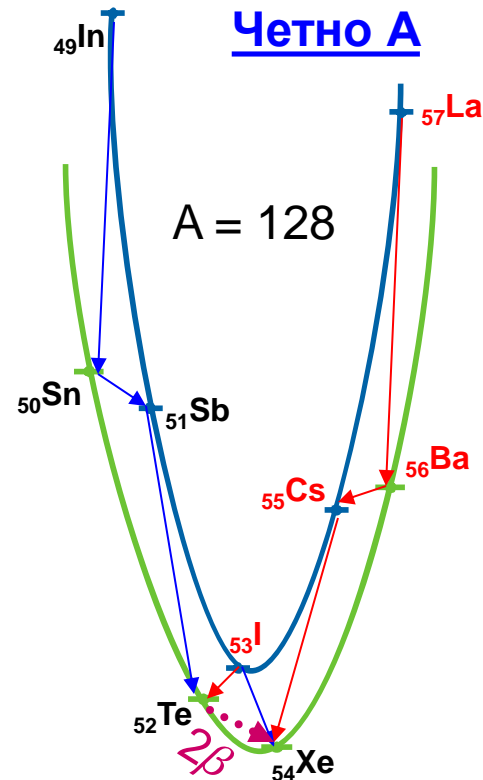
$$\left(\frac{\partial m(Z, A)}{\partial Z} \right)_{A=\text{const}} = 0$$

$$Z_{\min} \xrightarrow{A < 40} \frac{A}{2} \quad Z_{\min} < \frac{A}{2}$$

Нечетно A



Четно A



Естествена радиоактивност

$4n + 1$ (Нептуниева) – $^{237}\text{Np}(2.14 \times 10^6 \text{y}) \rightarrow \dots \rightarrow ^{209}\text{Bi}$

$4n + 2$ (Уранова) – $^{238}\text{U}(4.47 \times 10^9 \text{y}) \rightarrow \dots \rightarrow ^{222}\text{Rn}(3.8\text{d}) \rightarrow \dots \rightarrow ^{206}\text{Pb}$

$4n + 3$ (Актиниева) – $^{235}\text{U}(7.04 \times 10^8 \text{y}) \rightarrow \dots \rightarrow ^{207}\text{Pb}$

Други

^{40}K ($1.28 \times 10^9 \text{y}$)

^{87}Rb ($4.8 \times 10^{10} \text{y}$)

^{113}Cd ($9 \times 10^{15} \text{y}$)

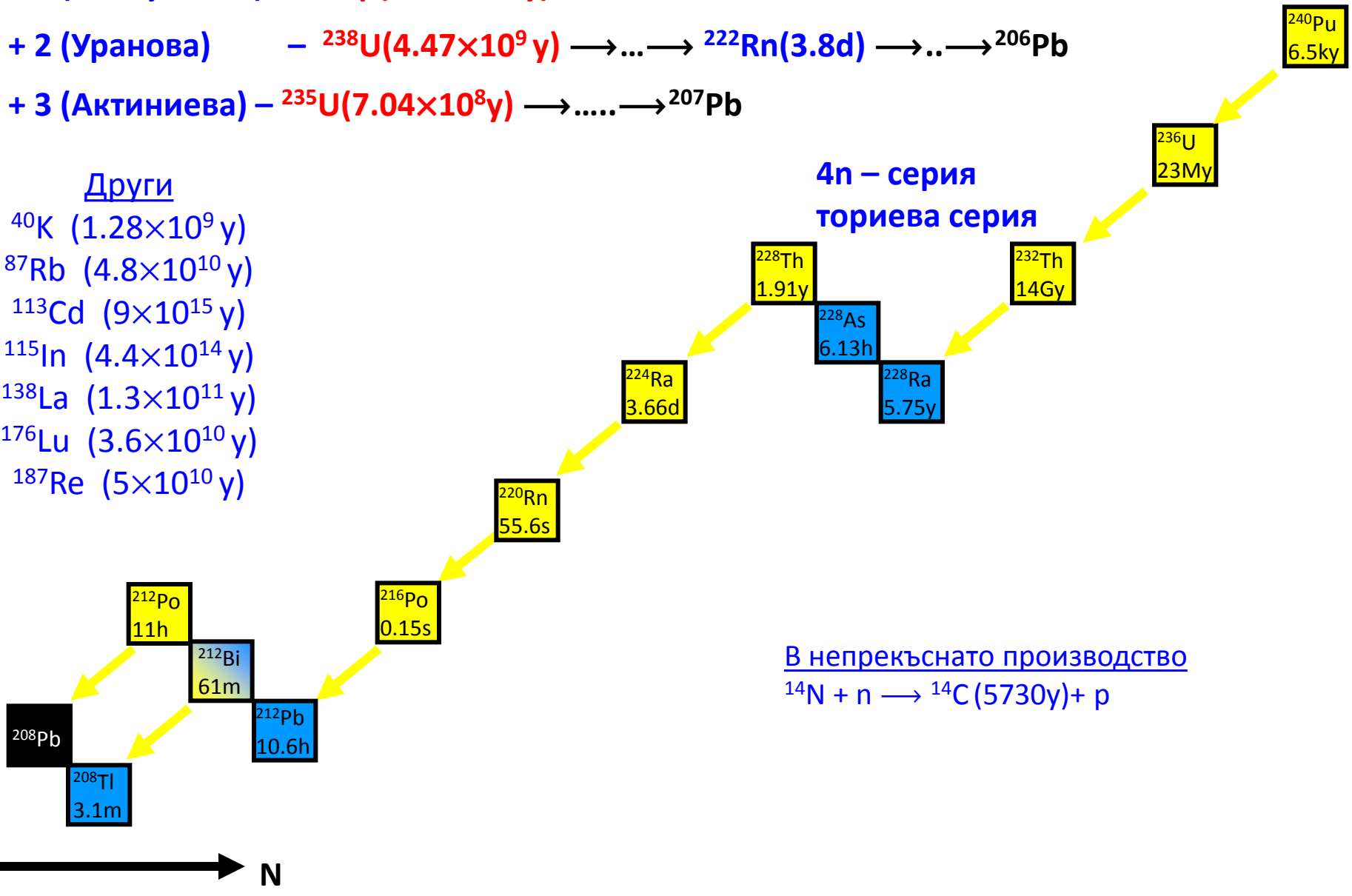
^{115}In ($4.4 \times 10^{14} \text{y}$)

^{138}La ($1.3 \times 10^{11} \text{y}$)

^{176}Lu ($3.6 \times 10^{10} \text{y}$)

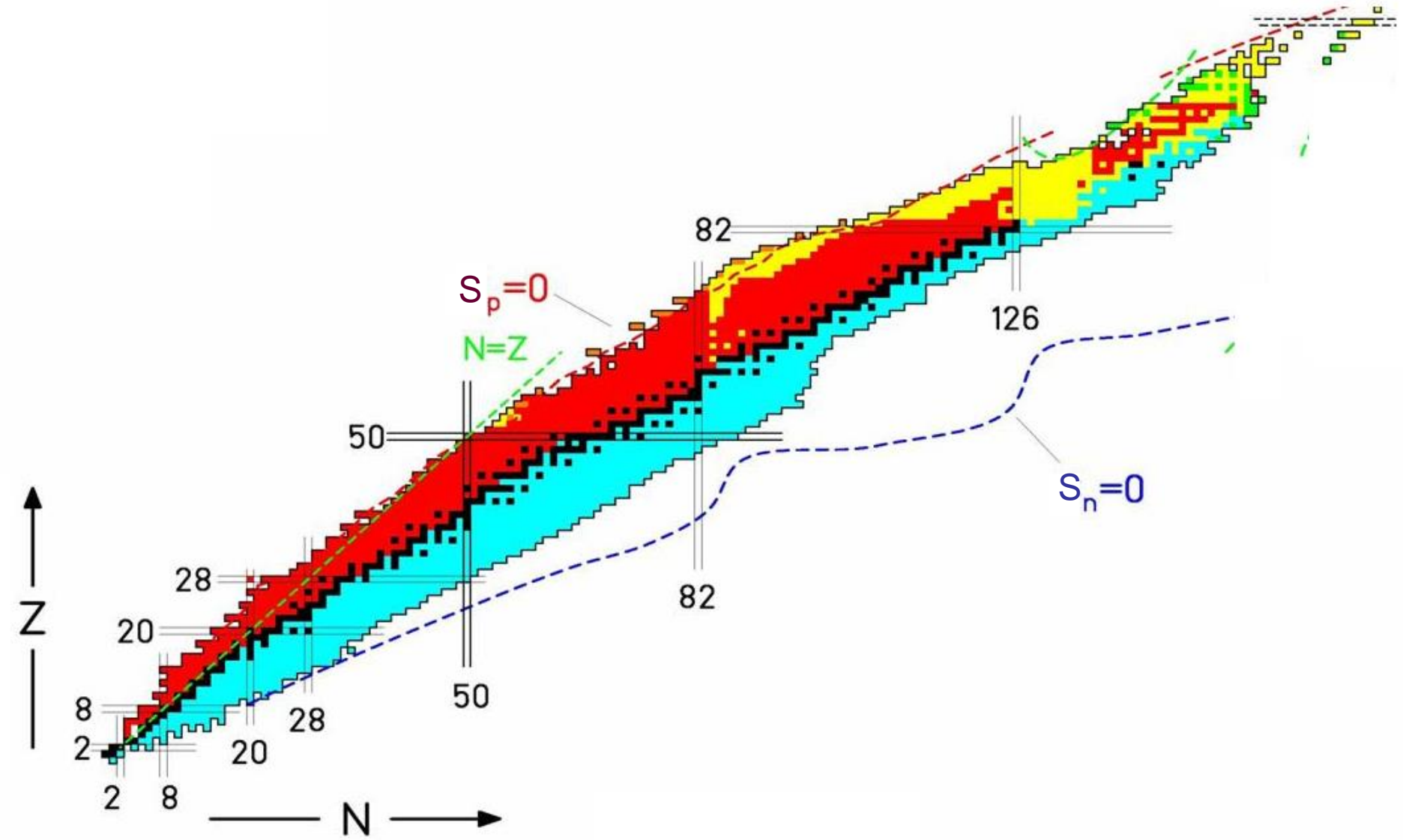
^{187}Re ($5 \times 10^{10} \text{y}$)

$4n$ – серия ториева серия

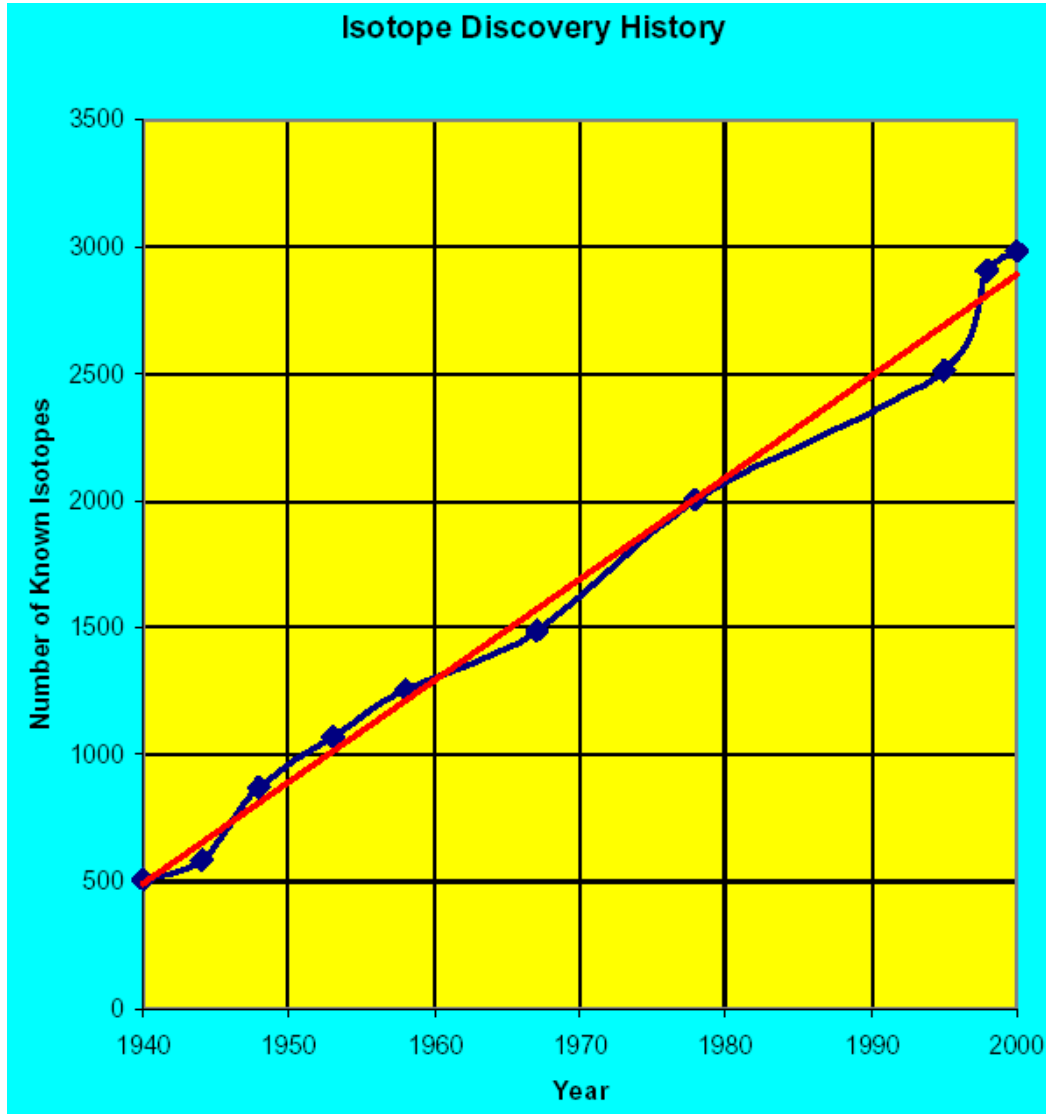


В непрекъснато производство
 $^{14}\text{N} + n \rightarrow ^{14}\text{C} (5730\text{y}) + p$

Граници на съществуване ядрената материя



Карта на нуклидите



- До днес са идентифицирани над **3000** нуклида;
- От тях само **284** са стабилни;
- Известни са 118 химични елемента (потвърдени до **Z=116** Lv – Livermorium
Z=117 Ts – Tennessine
Z=118 Og – Oganesson);

Благодаря за вниманието!