New Jersey Center for Teaching and Learning

Progressive Science Initiative

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Nuclear Physics

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How to Use this File

- Each topic is composed of brief direct instruction

- There are formative assessment questions after every topic denoted by black text and a number in the upper left.

  > Students work in groups to solve these problems but use student responders to enter their own answers.

  > Designed for SMART Response PE student response systems.

  > Use only as many questions as necessary for a sufficient number of students to learn a topic.

- Full information on how to teach with NJCTL courses can be found at njctl.org/courses/teaching methods

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Nuclear Structure

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The Nucleus

Protons and neutrons are called nucleons. Originally they were thought to be fundamental - indivisible - particles, but were later found to be comprised of 3 quarks each.

There are six types of quarks with different properties! The proton is made up of 2 up quarks and 1 down quark. The neutron is made up of 1 up quark and 2 down quark.

This explains why the neutron and proton masses are slightly different and why the proton has a positive charge and the neutron is neutral.

	Charge	Mass
Proton	1.6022×10^{-19} C	1.6726×10^{-27} kg
Neutron	0	1.6749×10^{-27} kg

Nomenclature

The number of protons in a nucleus is called the atomic number, and it is designated by the letter Z.

The number of nucleons in a nucleus is called the atomic mass number, and it is designated by the letter A.

The neutron number, N, is given by N = A - Z.

To specify a nuclide we use the following form:

$${}_{Z}^{A}X \quad \text{or, Element name - A}$$

X is the chemical symbol for the element.

1 How many protons are in $^{107}_{47}Ag$?

Answer

http://njc.tl/rf

2 How many nucleons are in $^{107}_{47}Ag$?

Answer

http://njc.tl/rg

3 How many neutrons are in $^{107}_{47}Ag$?

Answer

http://njc.tl/rh

4 How many electrons are in non-ionized $^{107}_{47}Ag$?

Answer

Size of the Nucleus

Rutherford estimated the size of the nucleus by using the Conservation of Energy. He assumed a head on collision between an alpha particle and a gold nucleus, and that all of the alpha particle's Kinetic Energy would transform into Electric Potential Energy (U_E). The alpha particle would come to a momentary stop at a distance a little greater than the gold nucleus's radius (KE = 0 and U_E = max) before it rebounded.

This distance was calculated to be 3.2 x 10^{-14} m. Further experiments by other researchers showed that the radius of a nucleus with an atomic mass of A is:

$$r = r_0 A^{1/3}$$

$$r_0 = 1.2x10^{-15} m$$

http://njc.tl/rj

Size Comparisons

Nuclei have radii in the range of 10^{-15} m, so the femtometer, or fermi (named in honor of Enrico Fermi, who created the first self sustaining critical nuclear reaction) was defined as:

1 fm = 10^{-15} m.

Atoms have radii on the order of 10^{-10} m, so you can see just how small the nucleus is.

A word about the magnitude of the charge on the proton and the electron. It's exactly the same. And yet, the proton is 1836 times more massive than an electron.

Nuclear Energy Levels and Forces

Electrons were described both by the Bohr Model and the Schrodinger Equation as being in well defined energy levels. When the electrons moved between levels, they either absorbed or emitted a photon depending on whether they moved to a higher or lower energy level.

These photons can be in the infrared - visible light -ultraviolet - X-ray areas of the electromagnetic spectrum.

The structure depended mostly on the attractive Coulomb Force between the nucleus and the electrons - and a slight repulsive force between the electrons.

Nuclear Energy Levels and Forces

Nuclear Energy Levels are more complex.

There are very strong repulsive Electromagnetic (Coulomb) forces between the protons that are packed within a small volume. This force acts over an infinite distance, but decreases in magnitude with increasing distance.

The strong nuclear force provides the attractive force between neutron-neutron, proton-neutron and proton-proton. This force only acts over a distance of 10^{-15} m (the size of the nucleus), and actually increases in strength as nucleons get further away from each other up to the distance limit

Nuclear Energy Levels

The strong nuclear force opposes the repulsive Coulomb force and keeps the nucleus together.

The analysis of these competing forces creates a more complex energy level scheme.

But, just like the electron energy levels, the nucleons can move between energy levels. And when this occurs, very high energy photons, in the form of gamma rays are emitted or absorbed.

There is one more force in the nucleus - the weak nuclear force, which is responsible for radioactive decay that converts neutrons to protons. The gravitational force is to small to even be measured.

http://njc.tl/rj

5 What is the nuclear radius of Radium 226?

Answer

http://njc.tl/rk

6 What is the nuclear radius of Hydrogen (A=1)?

Answer

http://njc.tl/rl

7 What force tries to split apart the nucleus?

- A Strong Nuclear Force.
- B Weak Nuclear Force.
- C Electromagnetic Force.
- D Gravitational Force.

Answer

http://njc.tl/rm

8 What force keeps the nucleus together?

- A Strong Nuclear Force.
- B Weak Nuclear Force.
- C Electromagnetic Force.
- D Gravitational Force.

Answer

9 What force is responsible for radioactive decay?

- A Strong Nuclear Force.
- B Weak Nuclear Force.
- C Electromagnetic Force.
- D Gravitational Force.

Answer

http://njc.tl/ro

Isotopes

Nuclei with the same number of protons are the same element, but when they have different numbers of neutrons they are called isotopes.

For many elements, there are a few different isotopes that occur naturally. Isotopes of a single element mostly have the same chemical properties (depends on the number of electrons), but can have quite different nuclear properties.

Natural abundance is the percentage of an element that occurs as a certain isotope in nature.

Many isotopes that do not occur in nature can be created in a laboratory with nuclear reactions.

Atomic Mass

Atomic masses are specified in unified atomic mass units (u) which are defined by specifying that a neutral carbon atom with 6 protons and 6 neutrons has a mass of 12.000000 u.

Thus, 1 u = 1.6605×10^{-27} kg.

By using Einstein's mass-energy equivalence equation, $E=mc^2$, atomic mass units can be expressed in terms of MeV/c^2 (1 MeV = 1.602×10^{-13} Joules):

$$E = m_u c^2$$

$$m_u = \frac{E}{c^2} = \frac{m_u c^2}{c^2} = \frac{(1.66054x10^{-27}\,kg)(2.99792x10^{8}\,m/s)^2}{c^2(1.60218x10^{-13}\,J/MeV)}$$

$$m_u = 931.5\,MeV/c^2$$

1 u = 1.6605×10^{-27} kg = $931.5\ MeV/c^2$

Atomic Mass

This table shows the rest masses (the object is at rest - it is not moving) for various parts of the atom.

	Rest Mass		
Object	**kg**	**u**	**MeV/c²**
Electron	9.1094×10^{-31}	0.00054858	0.51100
Proton	1.67262×10^{-27}	1.007276	938.27
Hydrogen Atom	1.67353×10^{-27}	1.007825	938.78
Neutron	1.67493×10^{-27}	1.008665	939.57

Atomic Mass

Because the atomic mass unit was defined for Carbon-12, that is the only isotope where the atomic mass (in u) is exactly equal to the number of protons plus neutrons.

For other elements, their exact, measured atomic mass is slightly different from the number of protons plus neutrons.

Atomic Mass

The Atomic Mass listed on the Periodic Table is a weighted average of the isotopes of each element.

For example, Carbon has 15 known isotopes with neutron numbers ranging from 2 to 16. There are two stable isotopes that make up, to two decimal places, 100% of the Carbon on earth (the other isotopes are present in trace amounts).

Carbon-12 98.93% relative abundance
Carbon-13 1.07% relative abundance

Atomic Mass = (.9883 x 12) + (.0107 x 13) = 12.01

This is the Atomic Mass that you will see on the Periodic Table.

10 Isotopes are elements that

- A have the same number of protons and neutrons but a different number of electrons.
- B have the same number of neutrons and electrons but a different number of protons.
- C have the same number of protons and electrons, but a different number of neutrons.
- D have the same number of protons, neutrons and electrons, but different energy levels.

Answer

11 There are two isotopes of Chlorine that comprise almost 100.00% of the Chlorine on earth (there are 22 other trace isotopes). Chlorine-35 has a relative abundance of 75.78% and Chlorine-37 has a relative abundance of 24.22%. Calculate the Atomic Mass shown on the Periodic Table.

Answer

12 There are two isotopes of Carbon that comprise almost 100.00% of the Carbon on earth. Carbon 12 has a relative abundance of 98.93% and Carbon-13 has a relative abundance of 1.070%. Calculate the Atomic Mass shown on the Periodic Table.

Answer

Binding Energy and Mass Defect

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Binding Energy and Mass Defect

The total mass of a nucleus is always less than the sum of its constituent neutrons and protons.

Where has all this mass gone?

It has become energy - such as radiation or kineticenergy.

The difference between the total mass of the nucleons and the mass of the nucleus is called the total binding energy of the nucleus. In energy units, the total binding energy is given by: $E_b = \Delta mc^2$

This binding energy is the amount of energy needed to be put into the nucleus in order to break it apart into protons and neutrons.

http://njc.tl/rp

Binding Energy and Mass Defect

For example, if we want to calculate the mass defect and binding energy of a Boron isotope, ${}^{10}_{5}B$:

There are 5 protons, 5 electrons and 5 neutrons. Note how the mass of the Hydrogen atom, ${}^{1}_{1}H$, is used, as it includes the mass of the proton and the electron, just like the mass of the Boron isotope includes its electrons.

$$ {}^{1}_{0}n : 5 \times 1.008665u $$
$$ {}^{1}_{1}H : 5 \times 1.007825u $$
$$ {}^{10}_{5}B : 10.012937u $$

To calculate the mass defect:

$$ \Delta m = (5 \times 1.008665u) + (5 \times 1.007825u) - (10.012937u) $$
$$ \Delta m = 0.069513u $$

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Binding Energy and Mass Defect

To calculate the binding energy we start by converting Atomic mass units to either kg or MeV/c^2.

$$\Lambda m = 0.069513u\left(\frac{1.6605x10^{-27}\,kg}{1u}\right) = 1.1543x10^{-28}\,kg$$

$$\Delta m = 0.069513u\left(\frac{931.5\,MeV/c^2}{1u}\right) = 64.75\,MeV/c^2$$

The binding energy can then be in either Joules or MeV.

$$E = \Delta mc^2 = (1.1543\times10^{-28}\,kg)(3\times10^8\,m/s)^2 = 1.0388\times10^{-11}\,J$$

$$E = \Delta mc^2 = 64.75\frac{MeV}{c^2}\times c^2 = 64.75MeV$$

http://njc.tl/rp

13 What is the mass defect of $^{12}_{6}C$?

$^{12}_{6}C : 12.000000u$

$^{1}_{0}n : 1.008665u$

$^{1}_{1}H : 1.007825u$

Answer

http://njc.tl/rq

14 What is the binding energy (in Joules) of $^{12}_{6}C$?

$^{12}_{6}C : 12.000000u$

$^{1}_{0}n : 1.008665u$

$^{1}_{1}H : 1.007825u$

Answer

http://njc.tl/rr

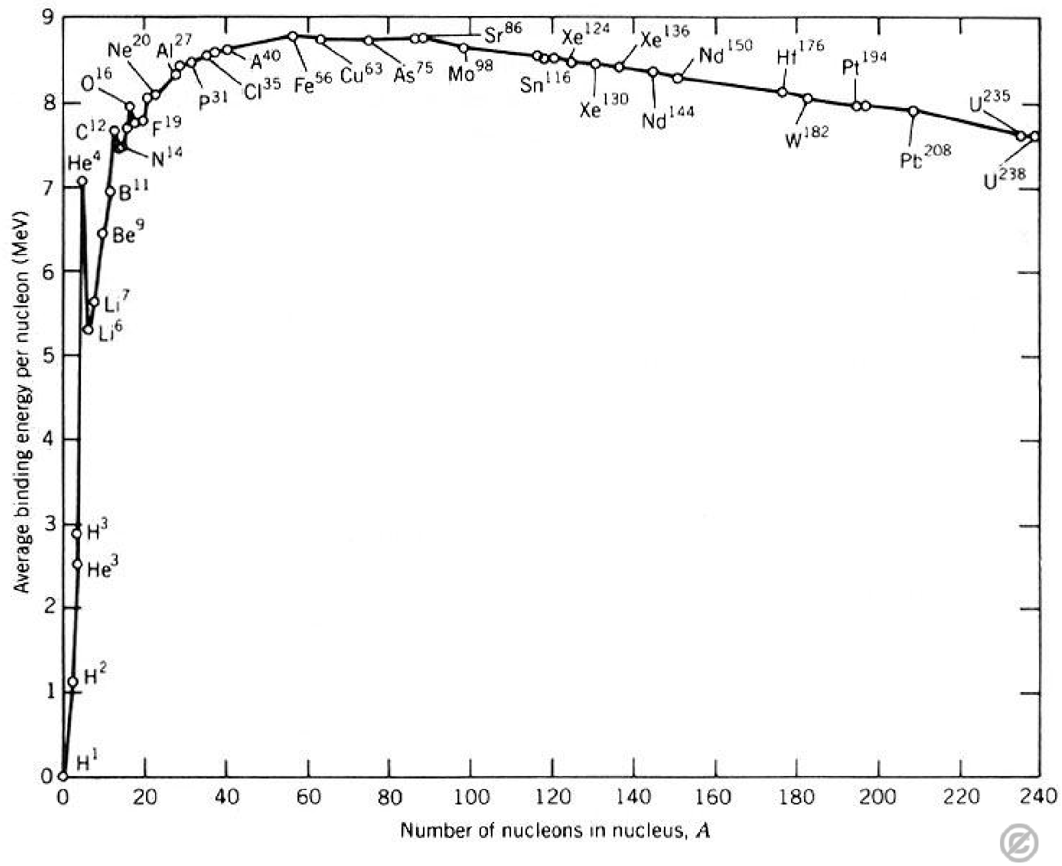
Binding Energy per Nucleon

An interesting result is obtained by plotting the Binding Energy per nucleon vrs. nucleon number.

The curve peaks at Iron-56 (new research suggests the peak is at Nickel-62). There is structure in the curve below that mark due to the the energy levels of the different nuclei. Helium-4 has a relatively high Binding Energy/Nucleon, indicating that it is very stable compared to its neighboring nuclei.

Nuclear Binding Energies are on the order of one million times greater than electron binding energies - that's why nuclear reactions involve so much more energy than chemical reactions.

Binding Energy per Nucleon



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Binding Energy per Nucleon

Elements to the left of Iron-56 on the curve are created in stars using a fusion reaction (nuclei are combined to form a larger nucleus, releasing the Binding Energy). These reactions release more energy than is put into the reaction, and that's what causes our sun to shine.

Elements to the right are created in the last stages of a star exploding (supernova). This is because they release less energy than the energy required to fuse smaller nuclei together. And this energy only occurs during the explosion.

15 Which of the following elements are created in the steady state operation of our Sun?

- A Uranium
- B Fermium
- C Radium
- D Helium

Answer

http://njc.tl/rt

16 Binding Energy is

- A the energy required to separate the nucleus into its constituent parts.
- B the energy required to split an atom into its constituent parts.
- C the energy that holds the electrons in orbit about the nucleus.
- D the energy that pushes the protons apart.

Answer

http://njc.tl/ru

Radioactivity

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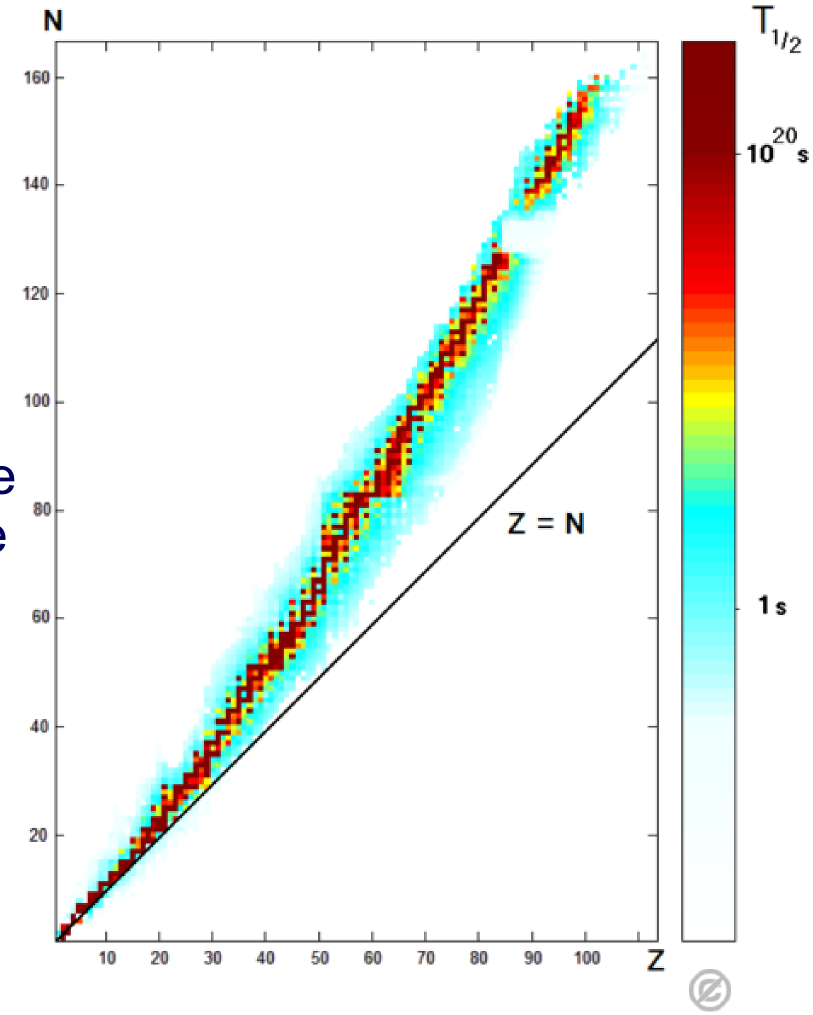
Nuclear Stability Curve

There are around 260 stable nuclear isotopes. The curve on the right plots N (neutron number) vrs. Z (proton number). The most stable nuclei are shown in red, with the least stable shown in blue.

More neutrons are required in stable higher mass nuclei - the short range nuclear force's ability to counteract the repulsive Coulomb force is reduced as the nucleus grows larger.



http://njc.tl/rv

Radioactivity

Non stable nuclei become stable nuclei by emitting radiation. This is called Radioactivity and was first observed and studied by Henri Becquerel, Marie Curie and Pierre Curie.

There are three types:

- Alpha particles, which are helium nuclei.
- Beta particles - a neutron is converted into a proton and emits an electron and an anti-neutrino. When a proton is converted into a neutron, it emits a positron (postively charged electron) and a neutrino. The beta particles are these electrons and positrons emitted from the nucleus.
- Gamma rays - high energy (high frequencey) electromagnetic radiation released when an excited nucleus moves to a lower energy level and releases the excess energy in the form of a photon.

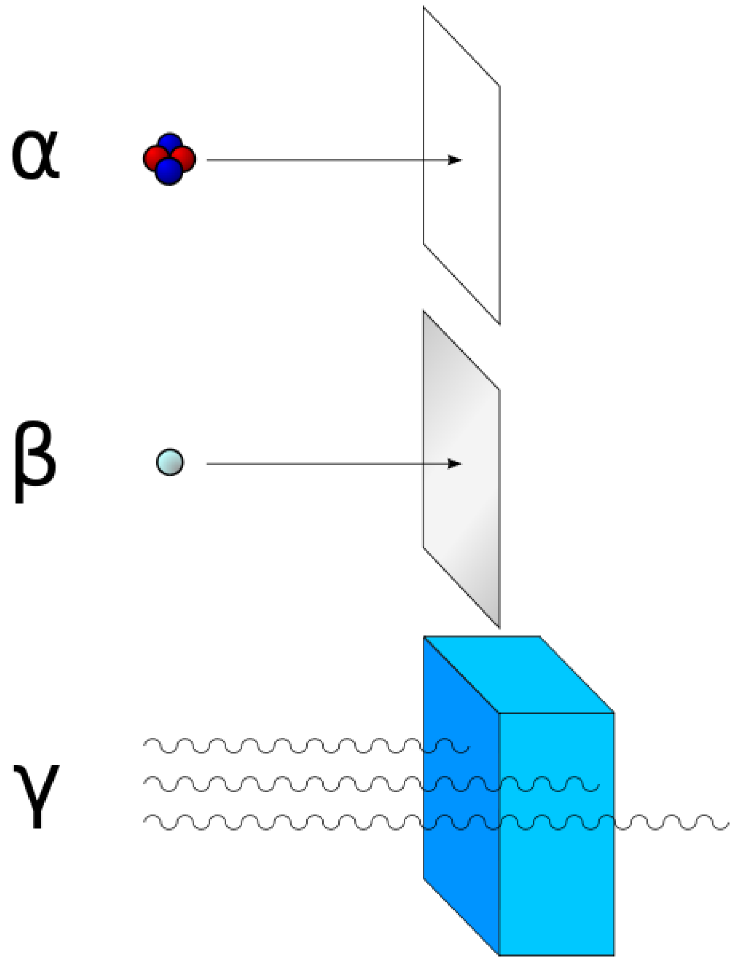
http://njc.tl/rv

Radioactivity Stopping Power

Alpha particles are stopped by a sheet of paper.

Beta particles are stopped by a thin sheet of aluminum.

Gamma rays are the most penetrating and are stopped by several meters of lead.



http://njc.tl/rv

Radioactivity

Elements will change into other elements due to radioactivity - this is called decay.

Medieval alchemists (not a real science) attempted to change base metals, such as lead, into more valuable gold, via chemical reactions.

This is not possible - only nuclear reactions such as radioactive decay, fission and fusion can accomplish this transmutation of elements into other elements.

Decay Nomenclature

Alpha Decay is when a nucleus emits a Helium nucleus (2 protons, 2 neutrons, 0 electrons, with a charge of +2e). It is represented as shown below:

$$^{A}_{Z}X \rightarrow\ ^{A-4}_{Z-2}Y +\ ^{4}_{2}He$$

Beta Decay is when a neutron converts into a proton and emits an electron and an anti-neutrino (to conserve momentum) A proton converts into a neutron and emits a positron and a neutrino.

$$^{A}_{Z}X \rightarrow\ ^{A}_{Z+1}Y + e^{-} + \overline{\upsilon}$$

$$^{A}_{Z}X \rightarrow\ ^{A}_{Z-1}Z + e^{+} + \upsilon$$

Gamma Radiation is the emission of a photon when an excited nucleus decays to a lower energy level.

$$^{A}_{Z}X^{*} \rightarrow\ ^{A}_{Z}X + \gamma$$

http://njc.tl/rv

Conservation of Nucleon Number

A Conservation Law applies to these decay schemes. The Law of the Conservation of Nucleon Number states that the total number of nucleons (A) remains constant for all nuclear reactions.

In the case of Beta decay, a neutron can change into a proton or a proton can change into a neutron - but the total number of nucleons stays constant.

Alpha Decay

An example of a nucleus that undergoes alpha decay isthe following isotope of polonium. We can find out what it decays into by balancing out the atomic (Z) and mass numbers (A).

$$^{212}_{84}Po \rightarrow \boxed{\;?\;} + {}^{4}_{2}He$$

Another example is Radium 218.

$$^{218}_{88}Ra \rightarrow \boxed{\;?\;} + {}^{4}_{2}He$$

http://njc.tl/rv

Beta Decay

Here are two examples of Beta Decay.

$$^{11}_{4}Be \rightarrow \boxed{?} + ^{0}_{-1}e$$

$$^{22}_{11}Na \rightarrow \boxed{?} + ^{0}_{+1}e$$

http://njc.tl/rv

17 Which type of radiation is the hardest to shield a person from?

- A Alpha particles.
- B Beta particles.
- C Gamma rays.
- D X-rays.

Answer

18 Which type of radiation is stopped by the shirt you wear?

- A Alpha particles.
- B Beta particles.
- C Gamma rays.
- D X-rays.

Answer

http://njc.tl/rx

19 What is the missing component?

Students type their answers here

$$^{12}_{5}B \rightarrow {}^{12}_{6}C + ?$$

Answer

http://njc.tl/ry

20 What is the missing component?

Students type their answers here

$$^{190}_{84}Po \rightarrow \, ^{4}_{2}He + ?$$

Answer

http://njc.tl/rz

21 What is the missing component?

Students type their answers here

$$^{238}_{92}U \rightarrow {}^{234}_{90}Th + ?$$

Answer

http://njc.tl/s0

Nuclear Half-life

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Nuclear Half-life

A macroscopic sample of any radioactive substanceconsists of a great number of nuclei. These nuclei do not decay at one time.

The decay is random and the decay of one nucleushas nothing to do with the decay of any other nuclei.

The number of decays during a specific time period isproportional to the number of nuclei as well as the time period.

Mathematically, it is defined as an exponential decay. After each specific time period, half of the nuclei decay. This specific time period is called the isotope's <u>half-life</u>.

The isotopes of a specific element have very different half-lives; ng from μseconds to never decaying at all.

http://njc.tl/s1

Nuclear Half-life

The half life of an isotope is defined as the amount of time it takes for half of the original amount of the isotope to decay.

For example, find how much of a starting sample of 200 g of an isotope, whose half life is 2 years, is left after 6 years:

After 2 years (one half-life), 100 g are left.

After 4 years (two half-lives), 50 g are left.

After 6 years (three half-lives), 25 g are left.

A plot of sample mass versus time would result in an exponential decay curve.

Nuclear Half-life

Another way of solving this problem is to recognize that a time interval of 6 years will include 3 half-life periods of 2 years.

n = number of half-lives = 3
x = original sample size
y = sample size after 3 half-lives

The 2 in the denominator represents the sample size being cut in half after each half-life.

$$y = \frac{x}{2^n} = \frac{200g}{2^3} = 25g$$

22 The half life of an isotope is 5.0 seconds. What is the mass of the isotope after 30.0 seconds from a starting sample of 8.0 g?

Answer

23 The half life of an isotope is 3 hours. How long (in hours) will it take for a sample of 500.0 g to be reduced to 62.50 g?

Answer

Nuclear Reactions

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Nuclear Reactions

A nuclear reaction takes place when a nucleus (or particle) collides with another nucleus (or particle) and a change occurs in the nature of the nucleus or the particle.

For example:

$$ {}^{4}_{2}He + {}^{14}_{7}N \rightarrow {}^{17}_{8}O + {}^{1}_{1}H $$

Electrical charge, Nucleon number, Mass-Energy, Linear Momentum and Angular Momentum are all conserved in a nuclear reaction.

http://njc.tl/s4

Nuclear Reactions

A general reaction is written as:

$$a + X \rightarrow b + Y \quad \text{or} \quad X(a,b)Y$$

where a is the bombarding particle, X is the target nucleus, b is the product particle and Y is the recoil nucleus.

The reaction energy, or Q-value, is the energy available from the difference in mass of the reactants (a, X) and the products (b, Y).

$$Q = \left(M_a + M_X - M_b - M_Y\right)c^2 = \Delta m\left(931.5MeV/1u\right)$$

ere the mass defect $\Delta m = M_a + M_X - M_b - M_Y$

http://njc.tl/s4

Nuclear Reactions

Since mass-energy is conserved, Q is equal to the change in kinetic energy:

$$Q = KE_b + KE_Y - KE_a - KE_X$$

If Q is positive, the products have more kinetic energy (energy is released in the reaction). The reaction is exothermic, and more energy is released than is put into the reaction.

If Q is negative, the reactants have more kinetic energy (energy is absorbed in the reaction). The reaction is endothermic and more energy is put into the reaction then is released.

hold energy is the minimum energy necessary for the reaction ur.

http://njc.tl/s4

Nuclear Reactions

Find out if this reaction is exothermic or endothermic.

First fill in the missing component:

$$^{2}_{1}H + ^{14}_{7}N \rightarrow ^{3}_{2}He + \boxed{?}$$

Next, find the mass defect:

$$\Delta m = 2.014102u + 14.003074u - 3.016029u - 13.003355u = \boxed{?}$$

Find the reaction energy:

$$E = \Delta mc^2 = (-0.002207u)\left(\frac{1.6605x10^{-27}\,kg}{1u}\right)(2.9979x10^{8}\,m/s)^2$$

$$E = \boxed{?}$$

The reaction is $\boxed{?}$

http://njc.tl/s4

Nuclear Reactions

$$n + {}^{238}_{92}U \rightarrow {}^{239}_{92}U$$

$${}^{239}_{92}U \rightarrow {}^{239}_{93}Np + e^{-} + \overline{\nu}$$

$${}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu + e^{-} + \overline{\nu}$$

Neutrons are very effective in nuclear reactions.

They have no charge, so they are not repelled by the nucleus.

Physicists are able to create transuranic elements (elements with a greater atomic number than Uranium) by neutron bombardment.

This illustrates a chain of nuclear reactions started by Uranium-238 absorbing a neutron and then decaying.

http://njc.tl/s4

24 Compute the Q value of the reaction and state whether more energy is released than input into the reaction.

$${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{1}_{0}n + {}^{4}_{2}He$$

Answer

http://njc.tl/s5

25 Which of the following quantities are conserved in a nuclear reaction?

- A Mass-Energy.
- B Angular Momentum.
- C Charge.
- D All of the above.

Answer

http://njc.tl/s6

Nuclear Fission and Fusion

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Nuclear Fission

Enrico Fermi, Emilio Segre and associates bombarded uranium with neutrons in 1934 and observed beta particles, which indicated to them that heavier elements than Uranium were being formed.

Otto Han and Fritz Strassman, in 1938, showed that this bombardment resulted in the formation of Barium - a heavy nucleus, but still less massive than Uranium.

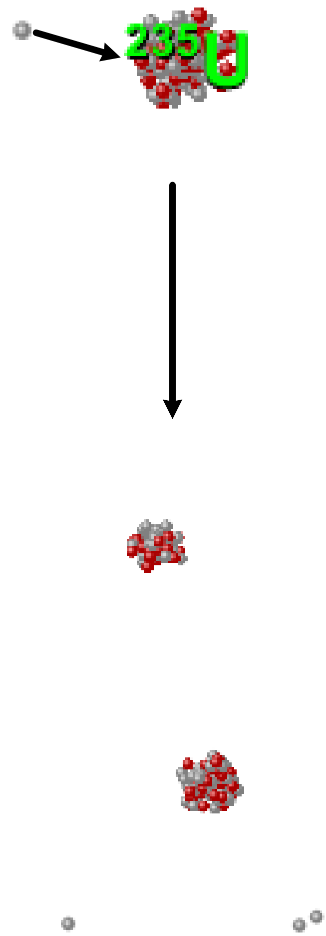
Lisa Meitner and Otto Frisch, in 1939, found that Uranium was undergoing a fission process, and smaller particles of similar size, like Barium and Krypton were being formed.

These particles would then decay via beta particle emission - and that's what Fermi, et.al. observed.

Nuclear Fission

Slow (thermal) neutrons were better at producing this nuclear fission, as the combination of their neutral charge and low energy allowed them to stay closer to the nucleus for a longer period of time.

When this happens, the thermal neutrons become part of the target nucleus, and the size of the nucleus grows such that some of the nucleons are outside the range of the strong nuclear force. The nucleus stretches out, until it splits apart, or fissions (Liquid Drop Model).



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Nuclear Fission

The target nucleus fissions into two nuclei of smaller masses and a number of neutrons.

The general equation for the fission of Uranium-235 is:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U^{*} \rightarrow X + Y + neutrons + Q$$

Where Q is the energy released in the reaction. Here are two examples of possible fission reactions.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U^{*} \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + Q$$

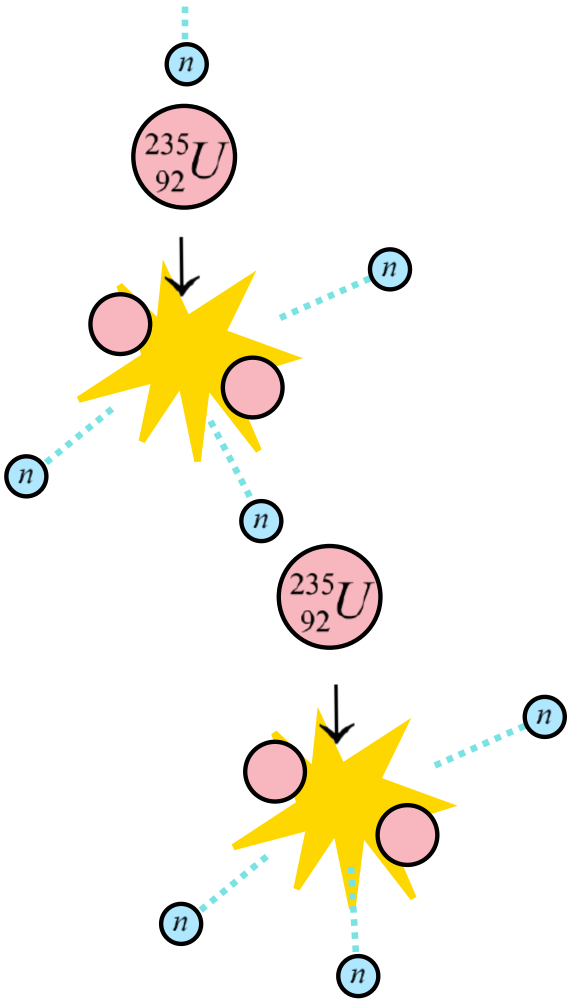
$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U^{*} \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2\,^{1}_{0}n + Q$$

Nuclear Fission

The energy release in a fission reaction is quite large. The smaller nuclei are stable with fewer neutrons, so multiple neutrons emerge from each fission.

The neutrons can be used to induce fission in surrounding nuclei, causing a chain reaction.

Enrico Fermi built the first self sustaining nuclear reaction in Chicago in 1942. Here's a nice simulation:



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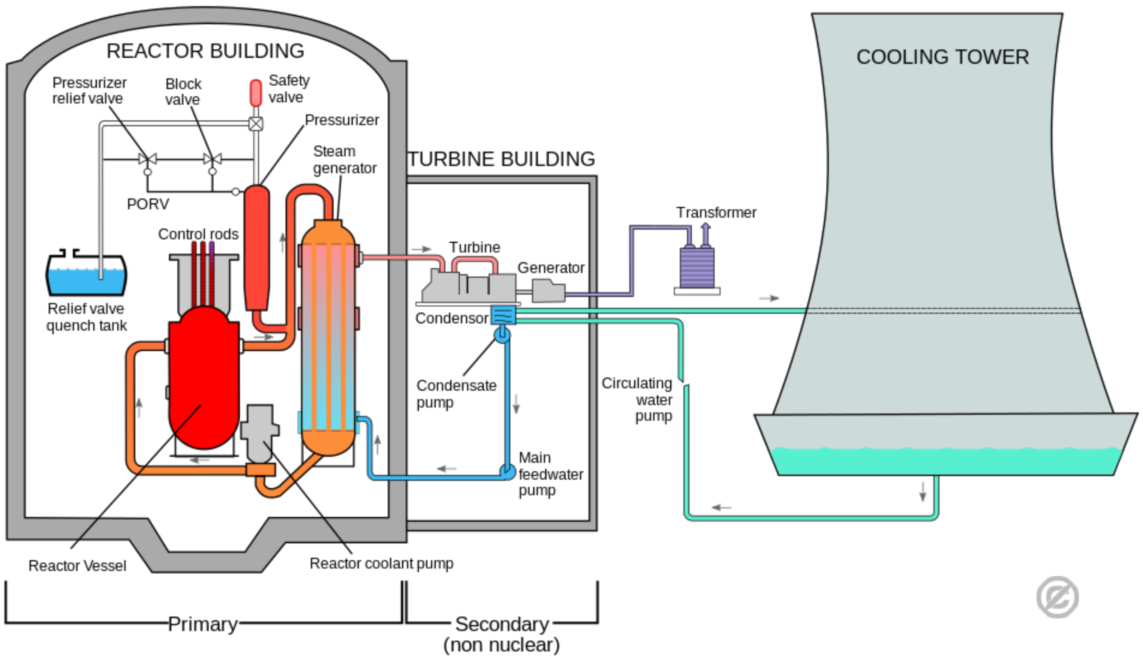
Nuclear Fission



This is a schematic of a nuclear power plant. The fission process occurs in the Reactor Vessel (red), which heats water in a primary hich boils water in the secondary loop. Then, you just have ar steam/turbine generator which generates electricity.

http://njc.tl/s7

Nuclear Fission

The reactor is controlled by regulating how many neutrons are free to strike other Uranium atoms. Cadmium and Boron control rods are excellent neutron absorbers and are carefully adjusted to absorb the right amount of neutrons to allow a self sustained, controlled reaction.

Critical Mass is the mass of the fissionable material that is required for nuclear fission to occur.

Nuclear reactors are designed with layers upon layers of safety features and there is no possible way for a reactor to ever cause a nuclear explosion.

Nuclear weapons are designed to explode in a massively uncontrolled chain reaction and are very, very different from a ear reactor.

http://njc.tl/s7

Nuclear Fusion

Hans Bethe, in 1938, postulated that the reason the sun doesn't cool down, despite the massive amounts of energy it was releasing, is due to Nuclear Fusion.

Nuclear Fusion is the combining of two lighter nuclei to form a larger nuclei which results in the release of more energy than was put into the reaction.

This occurs for elements on the first part of the Binding Energy/Nucleon chart where it has a positive slope. The heavier elements formed have a greater Binding Energy/Nucleon which implies a decrease in mass (Conservation of Mass-Energy), hence, a release of energy.

Nuclear Fusion

Here's the sequence of fusion reactions in the sun that lead to the formation of Helium, along with the energy released per reaction.

$$ {}_1^1H + {}_1^1H \rightarrow {}_1^2H + e^+ + \nu \qquad (0.42 MeV) $$

$$ {}_1^1H + {}_1^2H \rightarrow {}_2^3He + \gamma \qquad (5.49 MeV) $$

$$ {}_2^3He + {}_2^3He \rightarrow {}_2^4He + {}_1^1H + {}_1^1H \qquad (12.86 MeV) $$

http://njc.tl/s7

Nuclear Fusion

The net effect is to transform four protons into a helium nucleus plus two positrons, two neutrinos and two gamma rays.

$$4\,{}_{1}^{1}H \rightarrow {}_{2}^{4}He + 2e^{+} + 2\nu + 2\gamma$$

Very massive stars can create elements up to Iron via the fusion process.

Elements heavier than Iron are only created in supernova explosions as they require more energy input then is released in the fusion reaction.

Nuclear Fusion

Nuclear fusion requires an incredible amount of energy to start the reaction. In the sun, this energy comes from the high temperatures and pressures found in its core. This causes a plasma (the fourth state of matter, where atoms are highly ionized and electrons are separated from their nuclei) to form, which facilitates the reaction.

A Nuclear Fusion reactor would have great advantages over a Fission reactor. Its fuel (Hydrogen isotopes Deuterium and Tritium) is far more plentiful than Uranium-235, and it produces far less radioactive waste.

Nuclear Fusion

However, efforts to create fusion reactors, have not resulted in a reaction that provides more energy then is put into the reaction.

The problem is an engineering one - physical containers would melt due to the high temperatures of the plasma. Magnetic Fields are being used to control the plasma, but the energy required for the magnetic field creation is greater than the energy output of the fusion reaction.

26 What particle is used to strike Uranium-235 to create a sustainable chain reaction (nuclear fission)?

- A Proton.
- B Electron.
- C Positron.
- D Neutron.

Answer

27 What process do stars use to emit massive amounts of energy in the form of light and thermal energy?

- A Nuclear Fission.
- B Nuclear Fusion.
- C Chemical Reactions.
- D All of the above.

Answer

28 Nuclear fission reactions produce

- A Daughter nuclei with similar masses, and neutrons.
- B Daughter nuclei with similar masses, and protons.
- C Daughter nuclei with very different masses, and electrons.
- D Daughter nuclei with very different masses, and neutrons.

Answer

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29 What is the major factor preventing the development of nuclear fusion reactors?

- A A clear understanding of the physics.
- B The great danger from its radioactive products.
- C The difficulty in containing the plasma.
- D A shortage of reactant material.

Answer

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