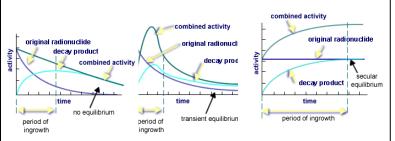
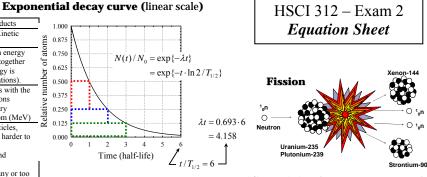
| Mass Defect ΔM equals the sum of the masses of reactants minus sum of the masses of the productsConservationTotal energy (E) and momentum $(p = mv)$ is conserved in all nuclear reactions. Kinetic energy may or may not be conserved. Mass may or may not be conserved.Binding Energy of the NucleusWhen two elementary particle or atoms combine to form a new atom, the reaction energy is the same as the energy required to balt the nucleus apart. Nuclear binding energy is much larger than electron binding energy (i.e. can be neglected in Q value calculations).Reactions (Chemical vs. Nuclear)Chemical reactions occur when the electron cloud associated with one atom reacts with the electron cloud of another atom (1 to 10 eV). Nuclear reactions occur when nucleons (neutrons and/or protons) interact: 1) Nucleus of two atoms interact; 2) Elementary particle interactions with nucleus; 3)Elementary particle interacts to form new atom (MeV)Q-valueWhen two or more particles, ions or atoms interact to form two or more other particles, ions or atoms, the reaction energy is termed the Q -value. Smaller Q values mean harder to remove the neutron and thus the nucleus is more stable. - How to handle <i>ions.</i> Q value computed before ion loses or acquires electron and becomes electrically neutral (explained below). - In many nuclear reactions, atoms are "borm" as positive or negative ions (too many or too few orbital electrons): $\frac{38}{17}$ Cl $\rightarrow \frac{38}{18}$ Ar ⁺ + $e^- + \overline{V}$. In this case, convert the ion to a neutral atom by: 1) adding an electron to both sides of equation; then 3) subtracting an electron from both sides of the equation resulting in $\frac{38}{17}$ Cl $\rightarrow \frac{38}{18}$ Ar + \overline{V} Fission vs. FusionFission relies on neutrons to split heavy nuclei and yields ~ 200 MeV per reaction; fusi | Term | Definitions | n | | | | |
|---|-----------------|---|------------|--|--|--|--|
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| e-How to handle ionsQ-value computed before ion loses or acquires electron and becomes electrically neutral (explained below). - Im many nuclear reactions, atoms are "born" as positive or negative ions (too many or too few orbital electrons): $\frac{1}{15} C_1 \rightarrow \frac{33}{15} A_1^+ \epsilon_{-7} \rightarrow 1$. Intis case, convert the ion to an existing electron on the same side of the equation. Then 3) subtracting an electron from both sides of the equation. Insuitum in $\frac{3}{12} (D_1 \rightarrow \frac{33}{15} A_1^+ + \bar{\tau})$ Fission vs. Fusion vs. Fusion relies on neutrons to split heavy nuclei and yields – 200 MeV per reaction. This on produces less energy but eliminates uncontrolled chain reactions and radioactive waste, and is thus desirable Nuclei in an excited state spontenously (and rapidly) transition back to the ground state. The energy appears as a high energy photon (γ -ray).Gamma Ray Camma-ray are emitted from the nucleus when a nucleon transition from an excited state to the ground state. The energy appears as a high energy form 0.01 MeV to 10 MeV to a lower energy of thermstrahum (γ -rays).Fu constraints and the nucleus when a nucleon transition from an excited state to a lower energy state. In: C6 dec.y, the "captured" electron usally constraint of the macleus when any electrons in carcel state to the ground state. The energy state. to a lower energy different bieware when kentice energy is to constraint on a higher orbit fill a vacancy. tasality or an instant on photoelectric effect. Electrons tasates, and are called characteristic x-rays. to a lower orbit in saving or a excited state where hincine energy is to constraint on a higher orbit fill a vacancy is a lower orbit is a source or frastate where kincit cenergy is constraved (darki scattering). Capture Scattering: neutron is absorbed into the nucleus. Nucleus is constraved (darki scattering) or an excited state where kinci | | | | | | | |
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| Q mate few orbital electrons: ${}^{3}_{15} Cl \rightarrow {}^{3}_{15} \Lambda r^+ + e^- + \overline{v}$. In this case, convert the ion to a neutral atom by: 1) adding an electron to both sides of equation; then 3) subtracting an electron from both sides of the equation. The solution: then 3) combine the ion with an existing electron on the same side of the equation; then 3) subtracting an electron fusion from both sides of the equation. The solution ${}^{33}_{15} Cl \rightarrow {}^{33}_{15} Al + \overline{v}$ Fission vs. Fission relies on neutrons to split heavy nuclei and yields - 30 MeV per reaction. This on produces less energy but eliminates uncontrolled chain reactions and radioactive wate, and is thus desirable. The energy appears as a high energy followin (r-ray). Gamma Ray Camma-rays are emitted from the nucleus when a nucleon transitions from an excited state to the ground state. The energy state is 1C (or brows radial in any magnetic field; Photons generated when an electron is accelerated in any magnetic field; Photons generated when the nucleus when energy state (c) (c) by the solution (r-ray). Fi Characteristic Characteristic x-rays are emitted when electrons transition from an excited state to the ground state. The energy state (c) (c) (c) the solution (r-ray). Fi Characteristic When an electron is abed of the eque, the complex of the solution of the solution (r-ray). Fi Auger Characteristic x-rays are emitted when lectrons transition from an excited state to the alover energy state. In C(d) the same only to relum to the ground state. Alp te view of the intermotion is high or the fifth the xore energy is a concorrest of entire x-rays. Fi Auger W | | | | | | | |
| neutral atom by: 1) adding an electron to both sides of equation; then 2) Combine the ion with an existing electron on the same side of the equation; then 3) subtracting an electron from both sides of the equation resulting in $\frac{35}{15}$ C1 \rightarrow $\frac{35}{15}$ Ar + \overline{y} Fission V: FusionFission relies on neutrons to split heavy nuclei and yields $- 200$ MeV per reaction; fusion joins lighter nucleical adyields $- 30$ MeV per reaction fusion produces less energy but eliminates uncontrolled chain reactions and radioactive waste, and is thus desirableExcited StateNuclei in an excited state spontaneously (and rapidly) transition back to the ground state. The energy appears as a high energy photon (γ -ray).Gamma RayCharacteristic energy state. In C2 decs., the "capture electron standing a-rays)Characteristic x-RayCharacteristic x-rays are emitted from the nucleus when a nucleon transitions from an excited state to a lower energy state. In C2 decs., the "capture" electron standing x-rays)Characteristic x-RayWhen an electron is accelerated (higher electron standing x-rays)Characteristic x-RayWhen an electron in a higher orbit fills a vacancy in a lower energy states) fill the vacancy. usually emitting a photon. Photon energy equals the energy of an excited state where kinetic energy in to conserved (<i>dustic scattering</i>) or an excited state where kinetic energy in to conserved (<i>dustic scattering</i>) or an excited state where kinetic energy is to conserved (<i>dustic scattering</i>) or an excited state where kinetic energy is to conserved (<i>dustic scattering</i>) or an excited state where kinetic energy is to conserved (<i>dustic scattering</i>). <i>Capatra</i> (<i>dustic scattering</i>), in the state state where kinetic energy is to conserved (<i>dustic scattering</i>) or an excited state w | Q-value | | •• | | | | |
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| Primordial Decay Series $\begin{bmatrix} 2 \\ \beta \\$ | | earth. Capture of secondary neutrons creates new radioactive isotopes. Most prominent of | I | | | | |
| Primordial Decay Series three long decay chains. 1) Thorium (Th), 2) Uranium (U), and 3) Actinium (Ac) series; Decay by α or β emission; Decay constant of the first member of the decay chain is very short, which means a very long half-life (billions of years); Daughter products are in secular equilibrium with parent (each member of the decay chain has the same activity) Singly Occurring 17 very long-lived radionuclides present in the environment, but not part of a decay chain. | Radionucides | | | | | | |
| Printotular Decay by α or β emission; Decay constant of the first member of the decay chain is very short, which means a very long half-life (billions of years); Daughter products are in <i>secular equilibrium</i> with parent (each member of the decay chain has the same activity) Singly Occurring | | | I | | | | |
| Decay Series short, which means a very long half-life (billions of years); Daughter products are in secular equilibrium with parent (each member of the decay chain has the same activity) Singly 17 very long-lived radionuclides present in the environment, but not part of a decay chain. Vccurring K 40 or dP 8.27 are the two more climiticates in terms of the member of the decay chain. | | | | | | | |
| Singly Occurring K 40 and Pb 87 are the two most similar to true of human exposure | Decay Series | short, which means a very long half-life (billions of years); Daughter products are in | | | | | |
| Occurring V 40 and Pb 87 are the two most spinsfront in terms of human exposure | Simoly | secular equilibrium with parent (each member of the decay chain has the same activity) | | | | | |
| | | | | | | | |
| | | K-40 and Rb-87 are the two most significant in terms of human exposure. | | | | | |
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What makes a good neutron shield? Specific activity (selected radioisotopes)

| • Pick a material that maximizes the energy loss per collision $f = \frac{4m_1m_2}{(m_1 + m_2)^2}$ | Isotope | Half-life unit | Specif TBq/g | ic Activity Ci/g |
|---|-------------------|----------------|-----------------|---------------------|
| $(m_1 + m_2)^2$ | ³ Н | 12.35 y | 357 | 9,649.71 |
| 4.1 | ¹⁴ C | 5730 y | 0.165 | 4.46 |
| Hydrogen (1 amu): $f = \frac{4 \cdot 1}{(1+1)^2} = 1$ (100%) | ¹⁸ F | 109.74 m | 3.52E+06 | 95,145,600.00 |
| (1+1) | ²² Na | 2.602 y | 231 | 6,243.93 |
| 4.12 | ³² P | 14.29 d | 1.06E+04 | 286,518.00 |
| Carbon (12 amu): $f = \frac{4 \cdot 12}{(1+12)^2} = 0.284$ (28.4%) | ⁶⁰ Co | 5.271 y | 41.8 | 1,129.85 |
| (1+12) | 90Sr | 29.12 y | 5.05E+00 | 136.50 |
| 4 206 | ⁹⁰ Y | 64 h | 2.01E+04 | 543,303.00 |
| Lead (206 amu): $f = \frac{4 \cdot 206}{(1 + 206)^2} = 0.0192 (1.92\%)$ | ¹³¹ | 8.04 d | 4.59E+03 | 124,067.70 |
| $(1+206)^2$ | ¹³⁷ Cs | 30 y | 3.22E+00 | 87.04 |
| Light elements (e.g., water) make better neutron shields than heavy elements! | ¹⁹² lr | 74.02 d | 3.40E+02 | 9,190.20 |
| | ²²⁶ Ra | 1600 y | 3.66E-02 | 0.99 |

Decay Constant = λ = Probability per unit time an atom decays

$$\triangleright \lambda = \sum_{i} \lambda_{i} = \lambda_{1} + \lambda_{2} + \lambda_{3} \{ competing \ processes \}$$

of Atoms =
$$N(t) = N_0 e^{-\lambda t}$$
...expected or avg. # of atoms at time, t
Half - Life = $T_{1/2} = -\frac{\ln(0.5)}{2} = \frac{\ln 2}{2} \cong \frac{0.693}{2}$

$$Hay = Lye = T_{1/2} = -\frac{1}{\lambda} = -\frac{1}{\lambda} = -\frac{1}{\lambda}$$

$$Avg. \ Lifetime = T_{av} \equiv \int_{0}^{\infty} dt \ tp(t) = \int_{0}^{\infty} dt \ t \ \lambda e^{-\lambda t} \ dt = \frac{1}{\lambda}$$

$$B_{avg} = \int_{0}^{\infty} dN(t) = \Delta V(t)$$

Rate of
$$Decay = \frac{dN(t)}{dt} = -\lambda N(t)$$

 $Activity = A \equiv \lambda N$
 $\triangleright A(t) = A_0 e^{-\lambda t}$
 $\triangleright 3.7 \times 10^{10} Bq = 1 Ci (1 g of ^{226} Ra)$
 $\triangleright 1 Ba = 1 dps = 1 \frac{decay}{dsintegration} = 1 \frac{disintegration}{dsintegration}$

$$\triangleright 1 Bq = 1 dps = 1 \frac{1}{second} = 1 \frac{1}{second}$$

Specific Activity =
$$\hat{A} \equiv \frac{A}{m}$$
...unique for each isotope
part emission note = particles decays = particles

Part. emission rate
$$= \frac{particles}{decay} \times \frac{aecays}{second} = \frac{particles}{second}$$

⊳

Energy release rate =
$$\sum_{i} \left(\frac{particles}{second} \times \frac{Energy}{particle} \right)_{i} = \frac{Energy}{second}$$

Decay w/Production =
$$N(t) = N_0 e^{-\lambda t} + \frac{Q_0}{\lambda} \left[1 - e^{-\lambda t} \right]$$
....production fluctuating

$$= Q_0 - \lambda N(t) \dots production \ constant$$

$$= N_{eq} = \frac{Q_0}{\lambda} \dots equilibrium$$

Saturation Activity = As
$$t \rightarrow \infty$$
, $A_{eq} = Q_0$unit : atoms / second

$$\triangleright \dots from A(t) = A_0 e^{-\lambda t} + Q_0 \left\lfloor 1 - e^{-\lambda t} \right\rfloor$$
$$\triangleright Q_0 = production \ rate$$
$$(1)^{t/T_{t/2}}$$

$$\begin{aligned} Radiodating &= \frac{N(t)}{N(0)} = e^{-\lambda t} \rightarrow t = -\frac{1}{\lambda} ln \left[\frac{N(t)}{N(0)} \right] = \frac{1}{\lambda} ln \left[\frac{N(0)}{N(t)} \right] \\ & \triangleright \ ^{14}C \ radiodating \ very \ common....good \ for \ \sim 57,000 \ yrs \\ & \triangleright \ t = \frac{1}{\lambda} ln \left[\frac{N(0)}{N(t)} \right] \\ & \triangleright \ t = -\frac{1}{\lambda} ln \left[\frac{mass(t)}{mass(0)} \right] \\ & \land t = \frac{1}{\lambda} ln \left[\frac{activity(0)}{activity(t)} \right] \end{aligned}$$

$$Any \ quantity \ proportional \ to \ N \ is \ valid \\ & \triangleright \ t = \frac{1}{\lambda} ln \left[\frac{activity(0)}{n(t)/N_s} \right] \\ & \triangleright \ t = \frac{1}{\lambda} ln \left[\frac{N(0)/N_s}{N(t)/N_s} \right] \dots relies \ on \ stable \ isotope \ to \ estimate \ N(0) \end{aligned}$$

 $\triangleright \text{ Nuclear BE values often expressed on a per nucleon basis} \Rightarrow \frac{BE(\frac{A}{Z}X)}{A}$

mass increases

mass decreases

ıss (u) ge ucleons or β^{-} Positron : ${}^{0}_{+1}e$ or e^+ or β^+

 $\triangleright \left\{ Alpha : {}_{2}^{4}He \text{ or } {}_{2}^{4}He^{2+} \text{ or } \alpha \right\}$