PHYSICS

BOOKS - VIKRAM PUBLICATION (ANDHRA PUBLICATION)

NUCLEI

Problems

1. Show that the density of a nucleus does not depend upon its mass number (density is independent of mass)

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2. Compare the radii of the nuclei of mass numbers 27 and 64.

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3. The radius of the oxygen nucleus $._8^{16}O$ is $2.8 \times 10^{-15} m$. Find the radius of lead nucleus $._{82}^{205}Pb$.

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4. Find the binding energy of $._{26}^{56} Fe$. Atomic mass of Fe is 55.9349u and that of Hydrogen is 1.00783u and mass of neutron is 1.00876u.

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5. How much energy is required to separate the typical middle mass nucleus $._{50}^{120} Sn$ into its constituent nucleons ? (Mass of $._{50}^{120} Sn = 119.902199u$, mass of proton = 1.007825u and mass of neutron = 1.008665u)

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6. Calculate the binding energy of an α-particle. Given that mass of proton = 1.0073 u, mass of neutron = 1.0087 u, and mass of α- particle = 4.0015 u.

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7. Find the energy required to split $._{8}^{16}O$ nucleus into four α - particles. The mass of an α- particle is 4.002603u and that of oxygen is 15.994915u.

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8. Calculate the binding energy per nucleon of $._{17}^{35}Cl$ nucleus. Given that mass of $._{17}^{35}Cl$ nucleus = 34.98000 u, mass of proton = 1.007825u, mass of neutron = 1.008665u and 1 is equivalent to 931 MeV.

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9. Calculate the binding energy per nucleon of $._{20}^{40}Ca$. Given that mass of $._{20}^{40}Ca$ nucleus = 39.962589 u, mass of a proton = 1.007825 u,, mass of Neutron = 1.008665 u and 1 u is equivalent to 931 MeV.

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10. Calculate

Mass defect,

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11. Calculate

Binding energy

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12. Calculate

The binding energy per nucleon of $._{6}^{12}C$ nucleus. Nuclear mass of $._{6}^{12}C = 12.000000u$, mass of proton = 1.007825 u and mass of neutron = 1.008665 u.

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13. The binding energies per nucleon for deuterium and helium are 1.1 MeV and 7.0 MeV respectively. What energy in joules will be liberated when 10^6 deuterons take part in the reaction.

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14. Bombardment of lithium with protons gives rise to the following reaction : $._3^7 Li + ._1^1 H \rightarrow 2[._2^4 He] + Q$. Find the Q - value of the reaction. The atomi mases of lithium, proton and helium are 7.016u, 1.0084 and 4.004 u respectively.

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15. The half life radium is 1600 years. How much time does 1g of radium take to reduce to 0.125 g.

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16. Plutonium decays with a half - life of 24,000 years. If plutonium is stored for 72,000 years, what fraction of it remains ?

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17. A certain substance decays to 1/232 of its initial activity in 25 days. Calculate its half-life.

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18. The half - life period of a radioactive substance is 20 days. What is the time taken for $7/8^{th}$ of its original mass to disintegrate ?

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19. How many disintegrations per second will Occur in one gram of $._{92}^{238}U$, if its half-life against α- decay is $1.42 \times 10^{-17}s$?

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20. The half-life of a radioactive substance is 100 years. Calculate in how many years the activity will decay to $1/10^{th}$ of its initial value.

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21. One gram of radium is reduced by 2 milligram in 5 years by α- decay. Calculate the half-life of radium.

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22. The half-life of a radioactive substance is 5000 years. In how many years, its activity will decay to 0.2 times α its initial value ? Given $\log_{10} 5 = 0.6990$.

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23. An explosion of atomic bomb releases an energy of $7.6 \times 10^{13} J$. If 200 MeV energy is released of fission of one $.^{235} U$ atom calculate (i) the number of uranium atoms undergoing fission, (ii) the mass of uranium used in the bomb.

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24. If one microgram of $._{92}^{235} U$ is completely destroyed in an atom bomb, how much energy will be released ?

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25. Calculate the energy released by fission from 2g of $._{92}^{235}U$ in kWh. Given that the energy released per fission is 200 MeV.

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26. 200 MeV energy is released when one nnucleus of $.^{235}U$ undergoes fission. Find the number of fissions per second required for fissions per second required for producing a power of 1 megawatt.

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27. How much $.^{235}U$ is consumed in a day in an atomic house operating at 400 MW, provided the whole of mass $.^{235}U$ is converted into energy ?

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Examples Textual

1. Given the mass of iron nucleus as 55.85 u and A = 56, find the nuclear density ?

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2. Calculate the energy equivalent of 1g of substance.

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3. Find the energy equivalent of one atomic mass unit, first in Joules and then in MeV. Using this, express the mass defect of $._8^{16}O$ in MeV/c^2.

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4. The half-life of $._{92}^{238}U$ undergoing α - decay is 4.5×10^9 years. What is the activity of 1g sample of $._{92}^{238}U$?

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5. Tritium has a half-life of 12.5 y undergoing beta decay. What fraction of sample of pure tritium will remain undecayed after 25 y.

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6. We are given the following atomic masses :

$._{92}^{238} U = 238.05079u$ $._{2}^{4} He = 4.00260u$

$._{90}^{234} Th = 234.04363u$ $._{1}^{1} H = 1.00783u$

$._{91}^{237} Pa = 237.05121u$

Here the symbol Pa is for the element protactinium (Z = 91) .

Calculate the energy released during the alpha decay of $._{92}^{238} U$.

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7. We are given the following atomic masses :

$._{92}^{238}U = 238.05079u$ $\quad$ $._{2}^{4}He = 4.00260u$

$._{90}^{234}Th = 234.04363u$ $\quad$ $._{1}^{1}H = 1.00783u$

$._{91}^{237}Pa = 237.05121u$

Here the symbol Pa is for the element protactinium (Z = 91) .

Show that $._{92}^{238}U$ cannot spontaneously emit a proton.

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Sample Problems

1. The half life of radium is 1600 years. How much time does 1g of radium take to reduce to 0.125 g.

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2. Plutonium decays with a half - life of 24,000 years. If plutonium is stored for 72,000 years, what fraction of it remains ?

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3. Explain the principle and working of a nuclear reactor with the help of a labelled diagram.

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4. Explain the source of stellar energy. Explain the carbon - nitrogen cycle, proton cycle occurring in stars.

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Very Short Answer Questions

1. What are isotopes and isobars ?

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2. What are isotopes and isomers ?

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3. What is a.m.u. ? What is its equivalent energy ?

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4. What will be the ratio of the radii of two nuclei of mass numbers A_1 and A_2 ?

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5. Natural radioactive nuclei are mostly nuclei of high mass number why ?

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6. Does the ratio of neutrons to protons in a nucleus increase, decrease or remain the same after the emission of an α - particle ?

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7. A nucleus contains no electrons but can emit them. How ?

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8. What are the units and dimension of the disintegration contant ?

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9. Why do all electrons emitted during β - decay not have the same energy ?

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10. Neutrons are the best projectiles to produce nuclear reactions. Why ?

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11. Neutrons cannot produce ionization. Why ?

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12. What are delayed neutrons ?

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13. What are thermal neutrons ? What is their importance ?

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14. What is the value of neutron multiplication factor in a controlled reaction and in an uncontrolled chain reaction ?

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15. What is the role of controlling rods in a nuclear reactor ?

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16. Why are nuclear fusion reactions called thermo nuclear reactions ?

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17. Define Becquerel and Curie.

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18. Explain the terms 'chain reaction' and 'multiplication factor'. How is a chain reaction sustained ?

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19. What is the function of moderator in a nuclear reactor ?

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20. What is the energy released in the fusion of four protons to form a helium nucleus ?

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Short Answer Questions

1. Why is the density of the nucleus more than that of the atom ? Show that the density of nuclear matter is same for all nuclei.

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2. Write a short note on the discovery of neutron.

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3. What are the properties of a neutron ?

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4. What are nuclear forces ? Write their properties.

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5. For greater stability a nucleus should have greater value of binding energy per nucleon. Why ?

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6. Explain α- decay ?

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7. Explain β - decay ?

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8. Explain γ - decay ?

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9. Define half life period and decay constant for a radioactive substance. Deduce the relation between them.

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10. Define average life of a radioactive substance. Obtain the relation between decay constant and average life.

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11. Deduce the relation between half life and average life of a radioactive substance.

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12. What is nuclear fission ? Given an example to illustrate it.

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13. What is nuclear fusion ? Write the conditions for nuclear fusion to occur.

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14. Distinguish between nuclear fission and nuclear fusion.

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15. Explain the terms 'chain reaction' and 'multiplication factor'. How is a chain reaction sustained ?

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Long Answer Questions

1. Define mass defect and binding energy. How does binding energy per nucleon vary with mass number ? What is its significance ?

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2. What is radioactivity ? State the law of radioactive decay. Show that radioactive decay is exponential in nature.

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Textual Exercises

1. Two stable isotopes of lithium $._3^6Li$ and $._3^7Li$ have respective abundances of 7.5% and 92.5%. These isotopes have masses 6.01512 u and7.01600 u, respectively. Find the atomic mass of lithium.

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2. Broron has two stable isotopes, $._5^{10}B$ and $._5^{11}B$. Their respective masses are 10.01294 u and 11.00931 u, and the atomic mass of boron is 10.811 u. Find the abundances of $._5^{10}B$ and $._5^{11}B$.

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3. The three stable isotopes of neon : $._{10}^{20}Ne, ._{10}^{21}Ne$ and $._{10}^{22}Ne$ have respective abundance of 90.51%, 0.27% and 9.22%. The atomic masses of the three isotopes are 19.99u, 20.99 u and 21.99 u, respectively. Obtain the average atomic mass of Neon.

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4. Obtain the binding energy (in MeV. Of a nitrogen nucleus $(._7^{14}N)$, given m $(._7^{14}N) = 14.00307u.$

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5. Obtain the binding energy of the nuclei $._{26}^{56}Fe$ and $._{83}^{209}Bi$in units of MeV from the following data :

$m\left(._{26}^{56}Fe\right) = 55.934939u, m\left(._{83}^{209}Bi\right) = 208.980388u$

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6. A given coin has a mass of 3.0 g. Calculate the nuclear energy that would be required to separate all the neutrons and protons from each other. For

simplicity assume that the coin is entirely made of

$._{29}^{63}Cu$ atoms of mass 62.92960 u..

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7. Write nuclear reaction equations for

α- decay of $._{88}^{226}Ra$

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8. Write nuclear reaction equations for

α- decay of $._{94}^{242}Pu$

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9. Write nuclear reaction equations for

β- decay of $._{15}^{32}P$

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10. Write nuclear reaction equations for

β- decay of $._{83}^{210}Bi$

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11. Write nuclear reaction equations for

β^+- decay of $._6^{11}C$

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12. Write nuclear reaction equations for

β^+- decay of $._{43}^{97}Tc$

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13. Write nuclear reaction equations for

Electron capture of $._{54}^{120}Xe$

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14. A radio active isotope has a half-life of T years. How long will it take the activity to reduce to

3.125%

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15. A radio active isotope has a half-life of T years. How long will it take the activity to reduce to

1% of its original value ?

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16. The normal activity of living carbon - containing matter is found to be about 15 decays per minute for every gram of carbon. This activity arises from the small proportion of radioactive $._{6}^{14}C$ present with the stable carbon isotope $._{6}^{12}C$. When the organism is dead, its interaction with the atmosphere (which maintains the above equilibrium activity. ceases and its activity begins to drop. From the know half-life (5730 years.) of $._{6}^{14}C$, and the measured activity, the age of the specimen can be approximately estimated. This is the principle of $._{6}^{14}C$ dating used in archaeology.

Suppose a specimen from Mohenjodaro gives an activity of 9 decays per minute per gram of carbon. Estimate the approximate age of the Indus-Valley civilisation.

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17. Obtain the amount of $._{27}^{60}Co$ necessary to provide a radioactive source of 8.0 mCi strength. The half-life of $._{27}^{60}Co$ is 5.3 years.

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18. The half-life of $._{38}^{90}Sr$ is 28 years. What is the disintegration rate of 15 mg of this isotope ?

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19. Obtain approximately the ratio of the nuclear radii of the gold isotope $._{79}^{197}Au$ and the silver isotope $._{47}^{107}Ag$.

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20. Find the Q-value and the kinetic energy of the emitted α - particle in the α - decay of

$._{88}^{226} Ra$

Given m $\left(._{88}^{226} Ra\right) = 226.02540u,$

$m\left(._{86}^{222} Rn\right) = 222.01750u,$

$m\left(._{86}^{222} Rn\right) = 220.01137u, m\left(._{84}^{216} Po\right)$

$= 216.00189u.$

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21. Find the Q-value and the kinetic energy of the emitted α - particle in the α - decay of

$._{86}^{220} Rn.$

Given m $\left(._{88}^{226} Ra\right) = 226.02540u,$

$m\left(._{86}^{222} Rn\right) = 222.01750u,$

$m\left(._{86}^{222} Rn\right) = 220.01137u, m\left(._{84}^{216} Po\right)$

$= 216.00189u.$

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22. The radionuclide $.^{11} C$ decays according to $._{6}^{11} C \rightarrow ._{5}^{11} B + e^{+} + v : T_{1/2} = 20.3$ min. The maximum energy of the emitted positron is 0.960 MeV. Given the mass values , $m\left(._{6}^{11} C\right) = 11.011434u$ and

$m\left(._{6}^{11}B\right) = 11.009305u$, calculate Q and compare it with the maximum energy of the positron emitted.

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23. The nucleus $._{10}^{23}Ne$ decays by β - emission. Write down the β - decay. Write down the β - decay equation and determine the maximum kinetic energy of the electrons emitted. Given that :

$m\left(._{10}^{23}Ne\right) = 22.994466u$

$m\left(._{11}^{23}Na\right) = 22.089770u$.

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24. The Q value of a nuclear reaction $A + b \rightarrow C + d$ is defined by $Q = [m_A + m_b - m_C - m_d]c^2$ where the masses refer to the respective nuclei. Determine from the given data the Q-value of the following reactions and state whether the reactions are exothermic or endothermic.

$._1^1 H + ._1^3 H \rightarrow ._1^2 H + ._1^2$

Atomic masses are given to be

$m(._1^2 H) = 2.014102u$

$m(._1^3 H) = 3.016049u$

$m\left(._{6}^{12}C\right) = 12.000000u$

$m\left(._{10}^{20}Ne\right) = 19.992439u$

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25. The Q value of a nuclear reaction $A + b \rightarrow C + d$ is defined by $Q = [m_A + m_b - m_C - m_d]c^2$ where the masses refer to the respective nuclei. Determine from the given data the Q-value of the following reactions and state whether the reactions are exothermic or endothermic.

$._{6}^{12}C + ._{6}^{12}C \rightarrow ._{10}^{20}Ne + ._{2}^{4}He$

Atomic masses are given to be

$m(._1^2 H) = 2.014102u$

$m(._1^3 H) = 3.016049u$

$m(._6^{12} C) = 12.000000u$

$m(._{10}^{20} Ne) = 19.992439u$

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26. Suppose we think of fission of a $._{26}^{56} Fe$ nucleus into two equal fragments, $._{13}^{28} Al$. Is the fission energetically possible ? Argue by working out Q of the process. Give $m(._{26}^{56} Fe) = 55.93494u$ and $m(._{13}^{28} Al) = 27.98191u$.

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27. The fission properties of $._{94}^{239} Pu$ are very similar to those of $._{92}^{238} U$. The average energy released per fission is 180 MeV. How much energy, in MeV, is released if all the atoms in 1kg of pure $._{94}^{239} Pu$ undergo fission ?

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28. A 1000 MW fission reactor consumes half of its fuel in 5.00 y. How much $._{92}^{235} U$ did it contain initially ? Assume that the reacotr operates 80% of the time that all the energy generated arises from the fission of $._{92}^{235}U$ and that this nuclide is consumed only by the fission process.

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29. How long can an electric lamp of 100W be kwpt glowing by fusion of 2.0 kg of deuterium ? Take fusion reaction as

$$._1^2H + ._1^2H \to ._2^3He + n + 3.27MeV$$

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30. Calculate the height of the potential barrier for a head on collision of two deuterons.

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31. Why is the density of the nucleus more than that of the atom ? Show that the density of nuclear matter is same for all nuclei.

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32. For the β^+ (positron) emission from a nucleus, there is another competing process known as electron capture (electron from an inner orbit, say, the K - shell, is captured by the nucleus and a neutrino is emitted).

$$e^+ \cdot {}_{Z}^{A}X \rightarrow \cdot {}_{Z-1}^{A}Y + v$$

Show that if β^+ emission is energetically allowed, electron capture is necessarily allowed but not vice-versa.

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Additional Exercises

1. In a periodic table the average atomic mass of magnesium is given as 24.312 u. The average value is based on their relative natural abundnce on earth. The three isotopes and their masses are $._{12}^{24}Mg(23.98504u)$, $._{12}^{25}Mg(24.98584u)$ and $._{12}^{26}Mg(25.98259u)$. The natural abundance of $._{12}^{24}Mg$ is 78.99% by mass. Calculate the abundances of other two isotopes.

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2. The neutron separation energy is defined as the energy required to remove a neutron from the nucleus. Obtain the neutron separation energies of the nuclei $._{20}^{41}Ca$ and $._{13}^{27}Al$ from the following data :

$m\left(._{20}^{40}Ca\right) = 39.962591u$

$m\left(._{20}^{41}Ca\right) = 40.962278u$

$m\left(._{13}^{26}Al\right) = 25.986895u$

$m\left(._{13}^{27}Al\right) = 26.981541u$

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3. A source contains two phosphorous radio nuclides $._{15}^{32}P(T_{1/2} = 14.3d)$ and $._{15}^{33}P(T_{1/2} = 25.3d)$. Initially, 10% of the decays come from $._{15}^{33}P$. How long one must wait until 90% do so ?

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4. Under certain circumstances, a nucleus can decay by emitting a particle more massive than an α - particle. Consider the following decay processes :

$.^{223}_{88}Ra \rightarrow .^{209}_{82}Pb + .^{14}_{6}C$

$.^{223}_{88}Ra \rightarrow .^{219}_{86}Pb + .^{4}_{2}He.$

Calculate the Q - value for these decays and determine that both are energetically allowed.

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5. Consider the fission of $.^{238}_{92}U$ by fast neutrons. In one fission event, no neutrons are emitted and the final end products, after the beta decay of the primay fragments, are $.^{140}_{58}Ce$ and $.^{99}_{44}Ru$. Calculate Q for this fission process. The relevant atomic and particle masses are

$m\left(._{92}^{238}U\right) = 238.05079u$

$m\left(._{58}^{140}Ce\right) = 139.90543u$

$m\left(._{44}^{99}Ru\right) = 98.90594u$

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6. Consider the D - T reaction (deuterium - tritium fusion)

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

Calculate the energy released in MeV in this reaction from the data :

$m\left(._{1}^{2}H\right) = 2.014102u$

$m\left(._{1}^{3}H\right) = 3.016049u$

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7. Consider the D - T reaction (deuterium - tritium fusion)

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

Consider the radius of both deuterium and tritium to be approximately 2.0 fm. What is the kinetic energy needed to overcone the Coluomn repulsion between the two nuclei ? To what temperature must the gas heated to initiate the reaction ?

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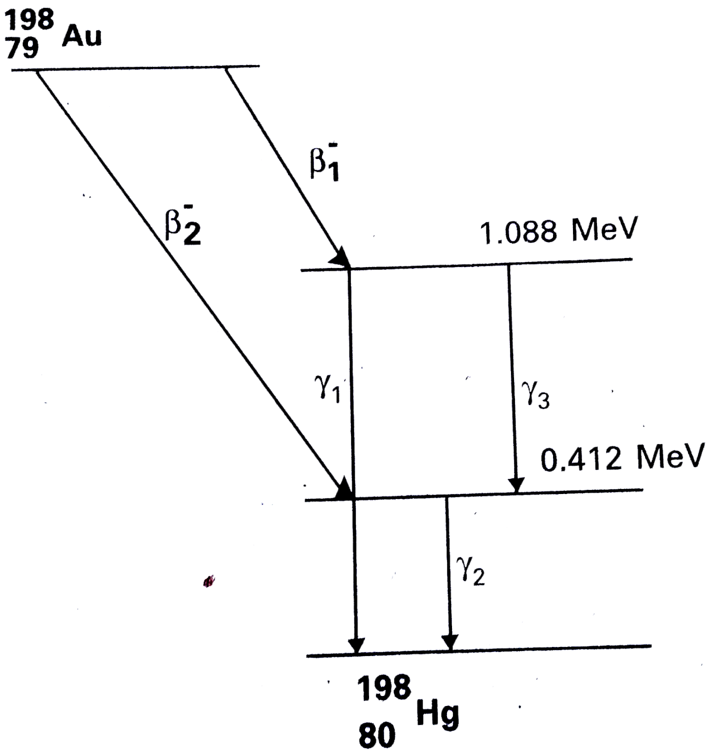
8. Obtain the maximum kinetic energy of β-particles, and the radiation frequencies of γ decays in the decay scheme shown in Fig. You are given that

$m(.^{198}Au) = 197.968233u$

$m(.^{198}Hg) = 197.966760u.$



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9. Calculate and compare the energy released by a. fusion of 1.0 kg of hydrogen deep within Sun and

b. the fission of 1.0 kg of $.^{235}U$ in a fission reactor.

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10. Suppose India a target of producing by 2020 AD, 2,00,000 MW of electric power, ten percent of which was to be obtained from nuclear power plants. Suppose we are given that, on an average, the efficiency of utilization i.e. conversion to electric energy. of thermal energy produced in a reactor was 25%. How much amount of fissionable uranium would our country need per year by 2020

? Take the heat energy per fission of $.^{235}U$ to be about 200 MeV.

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Dam Sure Vsaq

1. The half life of $.^{58}Co$ is 72 days. Calculate its average life.

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