Worksheet: Nuclear Binding Energy and Nuclear Reactions

Q1: A supernova explosion of a 2.00×10^{31} kg star produces 1.00×10^{44} J of energy.

Question Video

- How many kilograms of mass are converted to energy in the explosion?

A 1.11×10^{27} kg

B 1.33×10^{27} kg

C 7.11×10^{26} kg

D 3.70×10^{26} kg

E 3.33×10^{27} kg

- What is the ratio $\Delta m/m$ of mass destroyed to the original mass of the star?

A $5.56 \times 10^{-5} : 1$

B $4.05 \times 10^{-5} : 1$

C $3.28 \times 10^{-5} : 1$

D $2.32 \times 10^{-5} : 1$

E $6.35 \times 10^{-5} : 1$

Q2: Protons have a rest energy of 938.28 MeV, neutrons have a rest energy of 939.57 MeV, and electrons have a rest energy of 511 keV. Six hydrogen atoms and six neutrons are combined to form an atom of $^{12}_{6}C$. How much energy does this combination release if a unified atomic mass unit is equivalent to 931.494 MeV?

A 92.4 MeV

B 103 MeV

C 125 MeV

D 115 MeV

E 134 MeV

Q3: For the reaction, $n + ^{3}_{2}He \longrightarrow ^{4}_{2}He + \gamma$. Assume that the reactants are initially at rest.

- Find the amount of energy transferred to the $^{4}_{2}He$.

A 6.40×10^{-2} MeV

B 5.68×10^{-2} MeV

C 6.83×10^{-2} MeV

D 7.19×10^{-2} MeV

E 5.94×10^{-2} MeV

▸ Find the amount of energy transferred to the gamma-ray.

A 16.5 MeV

B 20.6 MeV

C 18.8 MeV

D 23.6 MeV

E 13.2 MeV

Q4: Calculate the binding energy per nucleon of ${}^{56}_{26}\text{Fe}$. Use a value of 55.9349 u for the atomic mass of ${}^{56}_{26}\text{Fe}$. Use a value of 1.0073 u for the rest mass of a proton, 1.0087 u for the rest mass of a neutron, and 0.00055 u for the rest mass of an electron.

A 8.79 MeV

B 4.23 MeV

C 14.1 MeV

D 17.6 MeV

E 11.5 MeV

Q5: The electrical power output of a large nuclear reactor facility is 900 MW. It has a 35.0% efficiency in converting heat released by nuclear reactions to electrical energy.

- What is the thermal power output?

A 2.57×10^3 MW

B 2.70×10^3 MW

C 2.12×10^3 MW

D 2.41×10^3 MW

E 2.28×10^3 MW

- How many ^{235}U nuclei undergo fission each second, assuming that the average energy released per fission is 200 MeV?

A 8.04×10^{19}

B 1.12×10^{20}

C 8.85×10^{19}

D 1.06×10^{20}

E 9.78×10^{19}

▸ What mass of ^{235}U is fissioned in 1 year of full-power operation?

A 991 kg

B 830 kg

C 449 kg

D 772 kg

E 603 kg

Q6: The power output of the Sun is 4×10^{26} W. 90% of the Sun's energy output is supplied by proton-proton chain reactions.

▸ If a proton-proton chain reaction produces 26.7 MeV from the fusion of four protons into a helium nucleus, how many protons are consumed per second?

A 5×10^{38}

B 10^{39}

C 3×10^{38}

D 8×10^{38}

E 10^{38}

▸ If a proton-proton chain reaction produces two neutrinos, how many neutrinos per second should there be per square meter at the surface of Earth from this process?

A 8×10^{14}

B 2×10^{15}

C 6×10^{14}

D 10^{15}

E 2×10^{14}

Q7: The reactions of the proton-proton chain are ${}^{1}_{1}H^{+}{}^{1}_{1}H{}^{2}_{1}H^{+}{}^{0}_{1}e^{+}{}_{e}$, ${}^{1}_{1}H$ + ${}^{2}_{1}H{}^{3}_{2}He + \gamma$, and ${}^{3}_{2}He + {}^{3}_{2}He{}^{4}_{2}H + {}^{1}_{1}H + {}^{1}_{1}H$. These reactions can be summarised as $4\,{}^{1}_{1}H{}^{4}_{2}He + 2\,{}^{0}_{1}e + 2\gamma + 2_{e}$. Use a value of 1.007825 for the atomic mass of ${}^{1}_{1}H$, use a value of 4.002603 u for the atomic mass of ${}^{4}_{2}H$, and use a value of 0.000549 u for the atomic mass of an electron. The gamma-ray photons produced in the reaction each have an energy of 0.511 MeV and the energy of the electron neutrino is negligible. How much energy is released in these reactions?

A 29.8 MeV

B 30.9 MeV

C 23.3 MeV

D 26.7 MeV

E 20.4 MeV

Q8: A nuclear power plant converts energy from nuclear fission into electricity with an efficiency of 35.0%. How much mass is destroyed in one year to produce a continuous 1 000 MW of electric power?

A 1.11 kg

B 1.16 kg

C 1.07 kg

D 1.00 kg

E 1.20 kg

Q9: The mass of subatomic particles contribute to the binding energy of nuclei. In determining the difference in binding energy between different nuclei, use a value of 1.0073 for the rest mass of a proton, 1.0087 u for the rest mass of a neutron, and 0.00055 for the rest mass of an electron.

▸ Using a value of 235.0493 u for the atomic mass of $^{235}_{92}U$, find its binding energy per nucleon.

A 7.48 MeV

B 7.57 MeV

C 7.53 MeV

D 7.67 MeV

E 7.61 MeV

▸ Using a value of 238.0508 u for the atomic mass of $^{238}_{92}U$, find its binding energy per nucleon.

A 7.29 MeV

B 7.59 MeV

C 7.41 MeV

D 7.68 MeV

E 7.50 MeV

Q10: Calculate the energy released in the neutron induced fission reaction

$$n + {}^{238}_{92}U \longrightarrow {}^{96}_{38}Sr + {}^{140}_{54}Xe + {}_3n.$$

Use a value of 238.050788 u for the atomic mass of $^{238}_{92}U$, use a value of 95.921750 u for the atomic mass of $^{96}_{38}Sr$, use a value of 139.92164 u for the atomic mass of $^{140}_{54}Xe$, and use a value of 1.0087 u for the rest mass of a neutron.

A 234.5 MeV

B 257.9 MeV

C 153.2 MeV

D 177.1 MeV

E 201.6 MeV

Q11: A 1.00-kg mass mixture of deuterium and tritium fuses to produce helium. There are equal numbers of deuterium and tritium nuclei in the mixture. The energy released by the reaction depends on the mass differences between deuterium, tritium, and neutrons and can be calculated using a value of 2.014102 u for the atomic mass of deuterium, 3.016049 u for the atomic mass of tritium, 4.002603 u for the atomic mass of helium, and 1.008701 u for the atomic mass of neutrons.

- How much energy is released by the fusion of the entire mixture?

A 3.37×10^{14} J

B 2.43×10^{14} J

C 4.45×10^{14} J

D 6.04×10^{14} J

E 7.92×10^{14} J

- If the reaction takes place continuously over exactly one year, what is the average power output from the reaction during that time?

A 10.7 MW

B 11.4 MW

C 12.0 MW

D 12.8 MW

E 13.6 MW

Q12: The sun produces energy at a rate of 3.85×10^{26} W by the fusion of hydrogen. About 0.7% of each kilogram of hydrogen goes into the energy generated by the Sun.

How many kilograms of hydrogen undergo fusion each second?

- A 5.99×10^{11} kg/s
- B 5.83×10^{11} kg/s
- C 6.14×10^{11} kg/s
- D 6.06×10^{11} kg/s
- E 5.90×10^{11} kg/s

If the sun is 90.0% hydrogen and half of this can undergo fusion before the sun changes character, how long could it produce energy at its current rate?

- A 4.90×10^{10} yr
- B 4.53×10^{10} yr
- C 5.02×10^{10} yr
- D 4.67×10^{10} yr
- E 4.79×10^{10} yr

How many kilograms of mass is the sun losing per second?

A 4.46×10^9 kg

B 4.33×10^9 kg

C 4.53×10^9 kg

D 4.27×10^9 kg

E 4.40×10^9 kg

What fraction of the Sun's mass will it have lost after the Sun has fused half of its hydrogen?

A 0.58%

B 0.41%

C 0.66%

D 0.32%

E 0.50%

Q13: A person accidentally touches a 220 V AC power source and draws a current from it.

▸ What current is drawn if the person is standing on a rubber mat that has a total resistance of 420 kΩ?

A	6.74×10^{-4} A
B	5.24×10^{-4} A
C	4.32×10^{-4} A
D	7.63×10^{-4} A
E	5.00×10^{-4} A

▸ What current is drawn if the person is standing on wet grass that has a total resistance of 2 000 Ω?

A	12.3 A
B	0.110 A
C	4.00 A
D	3.20 A
E	4.22 A

Q14: Seawater can be used in nuclear fusion reactions. The total energy available for fusion from the world's seawater can be assumed to be 2.5×10^{33} J, taking a value of 1 027 kg/m^3 for the densityof seawater.

▸ What would be the decrease in mass of the world's seawater?

A 8.3×10^{18} kg

B 2.8×10^{16} kg

C 2.8×10^{22} kg

D 5.6×10^{20} kg

E 8.3×10^{24} kg

▸ What would be the decrease in the volume of the world's seawater?

A 8.1×10^{15} m^3

B 2.7×10^{13} m^3

C 2.7×10^{19} m^3

D 5.5×10^{17} m^3

E 8.1×10^{21} m^3

Q15: Suppose an average home requires 600 kWh of electrical energy per month, and this power is produced by the destruction of a 0.90 g mass of matter converted to electrical energy with an efficiency of 48.0%.

For how long would the mass destroyed supply the required power?

- A 18.0×10^6 months
- B 180×10^6 months
- C 18.0×10^3 months
- D 180×10^3 months
- E 1.80×10^3 months

How many homes could be supplied for one year by the energy from the mass conversion?

- A 1.50×10^6 houses
- B 150×10^6 houses
- C 1.50×10^3 houses
- D 150×10^3 houses
- E 15.0×10^4 houses

Q16: Find the energy emitted in the β^- decay of Co$-_{60}$, given that the atomic mass of Co$-_{60}$ is 59.933819 u and that of Ni$-_{60}$ is 59.930788 u. Give your answer to 4 significant figures.

A 2.596 MeV

B 2.823 MeV

C 2.485 MeV

D 2.365 MeV

E 2.728 MeV

Q17: Calculate the mass equivalent in unified atomic mass units of the 13.6 eV binding energy of an electron in a hydrogen atom.

A 1.46×10^{-8} u

B 6.92×10^{-10} u

C 2.35×10^{-8} u

D 1.66×10^{-9} u

E 9.10×10^{10} u

Q18: 3.40×10^{30} MeV of energy is released in the annihilation of a sphere of matter and a sphere of antimatter of equal mass. What is the mass of each sphere?

A 5.60 kg

B 6.05 kg

C 3.03 kg

D 5.00 kg

E 4.03 kg

Q19: Calculate the energy released by the electron capture decay of ${}^{57}_{27}Co$, given that the atomic mass of Co-57 is 56.936296 u and that of Fe-56 is 56.935399 u.

A 0.836 MeV

B 0.535 MeV

C 0.830 MeV

D 0.320 MeV

E 1.35 MeV

Q20: Find the total energy released, in joules, if 2.00 kg of $^{235}_{92}U$ were to undergo fission, given that the average energy released per each fission is 200 MeV.

A 8.21×10^{13} J

B 2.05×10^{13} J

C 3.28×10^{14} J

D 1.64×10^{14} J

E 4.10×10^{13} J

Q21: A particle physicist discovers a neutral particle with a mass of 2.01723 u that he assumes is two neutrons bound together. Find the binding energy, using a value of 1.008664 u forthe mass of a neutron. State your answer to three significant figures.

A 102 keV

B 91.3 keV

C 66.8 keV

D 75.3 keV

E 82.5 keV

Q22: Answer the following questions using a value of 12.0107 u for the mass of $^{12}_{6}C$, 1.007276 u for the mass of a proton, 0.000549 u for the mass of an electron, and 1.008664 u for the mass of a neutron.

- What is the mass defect? Give your answer to 5 significant figures.

A 0.0000 u

B 0.088234 u

C 0.086520 u

D 0.089434 u

E 0.084940 u

- What is the binding energy? Give your answer to 4 significant figures.

A 0.000 MeV

B 82.19 MeV

C 83.31 MeV

D 80.59 MeV

E 79.12 MeV

Q23: Find the energy released in the following reaction, given that the atomic mass for He-3 is 3.016030, for He-4 is 4.002603, and for a neutron is 1.008665. Give your answer to four significant figures.

$$n + {}^{3}_{2}\text{He} \longrightarrow {}^{4}_{2}\text{He} + \gamma$$

A 15.32 MeV

B 931.5 MeV

C 20.58 MeV

D 32.68 MeV

E 919.0 MeV

Q24: The binding energy per nucleon tends toward its highest value for nuclei that have a mass number of around 60. Use a value of 1.007276 u for the mass of a proton, a value of 0.000549 u for the mass of an electron, and a value of 1.008664 u for the mass of a neutron.

▸ Calculate the diameter of a nucleus with a mass number of 60. Use a value of 1.2 fm for the radius of a proton.

A 9.4 fm

B 6.3 fm

C 4.7 fm

D 1.2 fm

E 8.5 fm

Find the binding energy per nucleon for ${}^{59}_{27}Co$, using a value of 58.9332 u for its atomic mass. Answer to three significant figures.

A 8.77 MeV

B 8.42 MeV

C 8.70 MeV

D 8.85 MeV

E 8.53 MeV

Find the binding energy per nucleon for ${}^{93}_{41}Nb$, using a value of 92.906378 u for its atomic mass. Answer to three significant figures.

A 8.66 MeV

B 8.72 MeV

C 8.44 MeV

D 8.57 MeV

E 8.29 MeV

Q25: A nucleus of ${}^{238}_{92}\text{U}$ undergoes alpha decay to thorium-234. Calculate the energy released, using a value of 238.050786 u for the initial mass of the nucleus, a value of 234.043583 u for the mass of the nucleus after it decays, and a value of 4.002603 u for the mass of the alpha particle. Give your answer to three significant figures.

A 1.95 MeV

B 4.28 MeV

C 2.36 MeV

D 1.25 MeV

E 3.29 MeV