Nuclear Fission and Fusion Assignment ***SOLUTIONS***

1.
$$m_i = 1.675\times10^{-27} + 3.9017\times10^{-25} = 3.91845\times10^{-25}\ \text{kg}$$
$$m_f = 2.28922\times10^{-25} + 1.57534\times10^{-25} + 3\times1.675\times10^{-27} = 3.91481\times10^{-25}\ \text{kg}$$
$$\therefore \Delta m = 3.64\times10^{-28}\ \text{kg lost}$$
$$E_b = \Delta m c^2 = 3.64\times10^{-28}\times\left(3.00\times10^8\right)^2 = 3.276\times10^{-11}\ \text{J released}$$
$$3.276\times10^{-11} \div 1.60\times10^{-19} = 2.0475\times10^{8}\ \text{eV released}$$
$$2.0475\times10^{8} \div 10^{6} = 204.75\ \text{MeV released}$$

The energy released is 3.28×10^{-11} J or 205 MeV (3 s.f.)

2. A fission reaction releases about 10^6 times more energy than a chemical reaction, and a fusion reaction releases 10 times more again.
3. Short-range nuclear attractive forces act only over a nucleon diameters whereas long-range coulomb repulsive forces act over the entire nucleus. When the nucleus is too big, the edges are being repelled but not sufficiently attracted and so the nucleus will stretch out. Once the elongation is sufficient, the two sections of the atom will be too distant to be held by the attractive forces and will break apart.
4.
   (a) The neutrons emitted as a result of nuclear fission have high speeds (since a large amount of energy is released during the reaction) corresponding to energies of 1 to 2 MeV. The energies needed for neutron capture are however much lower than this, for example ^{235}U undergoes fission with slow neutrons of energy of about 10 eV or less. Hence to induce fission in these nuclei the neutrons must be slowed down.

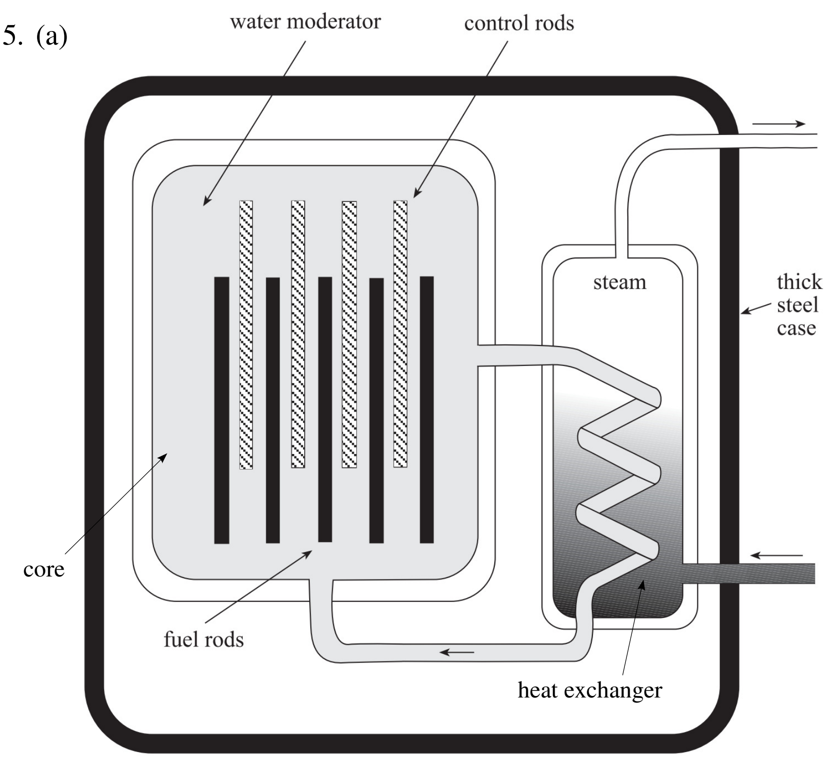
   (b) Conservation of momentum during a two-particle collision means that the smaller particle will always come away with more kinetic energy. If large particles were used for a moderator, it would take many more collisions for the neutron to pass its energy to the moderator. If the neutrons are absorbed by moderator nuclei then they will not be able to continue the chain reaction with the fission material.

   (c) The original nuclei had a high neutron-proton ratio in order to be more stable, and the new smaller nuclei do not need this high a ratio.

   (d) The excess of neutrons means the products are radioactive. In addition to this, the products of the decay of the products will be radioactive, and so on.

   (e) Uranium cannot be used for a continuous chain reaction unless it is enriched since natural uranium has so little ^{235}U that too many neutrons will absorbed into other uranium nuclei or lose their energy before reaching a uranium-235 nucleus.

5. (a)



(b)

- *fuel rods* – long thin tubes containing enriched uranium-235
- *moderator* – pressurised water, encloses fuel rods and slows down neutrons
- *control rods* – thin rods containing boron or cadmium, good absorbers of neutrons, can be lowered into the reactor to slow the reactions (this regulation is only possible because of the delay between neutron emissions)
- *heat exchanger* – the water moderator is heated up by the reactions in the core (meaning it acts as a coolant) and this heat energy is passed to a secondary coolant (also water) to produce steam to drive turbines which generate electricity
- *safety rods* (not shown on diagram) – a separate set of control rods that can be quickly dropped into the core during an emergency to shut down the reaction
- *shielding* – a thick steel case surrounded by very thick concrete (the steel stops particle radiation from eroding the concrete)

(c) The reactor is essentially operated by the raising and lowering of the control rods. To start the chain reaction, the control rods are partly withdrawn. This means that less neutrons are absorbed and more fissions take place. Once the reaction reaches the desired level of power, the control rods can be lowered. At normal operation the control rods are at such a point relative to the fuel rods and the moderator that on average each fission leads to one more fission. The reactions are of course producing more than one energetic neutron, but most are absorbed by the control rods.
To stop or slow the reactor, the control rods can be lowered deeper into the reactor. When enough neutrons are being absorbed the chain reaction will slow and eventually stop.

(d) The time interval between fissions caused by the delayed neutrons (10 or more seconds) is long enough to allow control rod movement to regulate the reactor behaviour.

(e)

Advantages of Nuclear Fission	**Disadvantages of Nuclear Fission**
No greenhouse gas emissions	Dangerous radioactive waste with long half-lives
Efficient (small amount of fuel can produce a large amount of energy)	Expensive safety measures must be adopted
Small volume of waste product	Disasters can be catastrophic
Reliable	

6.

$$m_i = 2\times 3.344\times 10^{-27} = 6.688\times 10^{-27} \text{ kg}$$

$$m_f = 5.008\times 10^{-27} + 1.675\times 10^{-27} = 6.683\times 10^{-27} \text{ kg}$$

$$\therefore \Delta m = 5\times 10^{-30} \text{ kg lost}$$

$$E_b = \Delta m c^2 = 5\times 10^{-30}\times\left(3.00\times 10^{8}\right)^2 = 4.5\times 10^{-13} \text{ J released}$$

$$4.5\times 10^{-13} \div 1.60\times 10^{-19} = 2.8125\times 10^{6} \text{ eV released}$$

$$2.8125\times 10^{6} \div 10^{6} = 2.8125 \text{ MeV released}$$

The energy released is 4.50×10^{-13} J or 2.81 MeV (3 s.f.)

7. The sun (and other stars) mainly produce their energy by fusion. The high temperatures within the stars provide the high kinetic energy required for hydrogen nuclei to overcome the coulomb repulsion and undergo fusion.

8.

Advantages

- The fuel (deuterium) is found in large quantities in the ocean.
- Not much radioactive waste produced (and the most common product, helium, is chemically inert).
- Reduced risk of meltdown or radioactive leakage. The fuel contained in the reaction chamber is only enough to sustain the reaction for about a minute, whereas a fission reactor contains about a year's supply of fuel. Fusion is not a chain reaction and therefore requires very extreme and precisely controlled conditions of temperature, pressure and magnetic field parameters to run. If the reactor were damaged, these would be disrupted and the reaction would rapidly extinguish.

Disadvantages

- To sustain a fusion reaction, extremely high temperatures must be reached. At the moment, we cannot maintain such temperatures for enough time to produce a continuous fusion reaction.