SPH3U UNIVERSITY PHYSICS

ENERGY & SOCIETY

☞ Nuclear Fission & Fusion (P.334-347)

Nuclear Reactions

When Ernest Rutherford split the atom for the first time in 1919, few would have predicted how profoundly our world would change. The footprint of the nuclear revolution of the 20th century can be found in areas ranging from medical advances, to nuclear power, to devastating weaponry.

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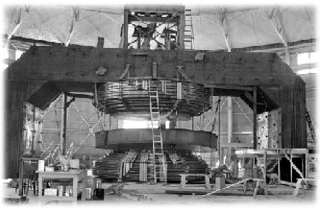
Nuclear Reactions

NOTE!

Many nuclear reactions can only occur when particles are travelling at speeds near to that of light. A cyclotron is a device capable of accelerating particles to these very high speeds. High-energy physics is the study of such interactions.



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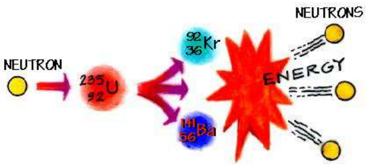
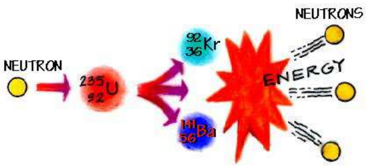
Nuclear Fission

*A reaction in which the nucleus of an atom is split into smaller pieces is known as **nuclear fission**. Nuclear fission differs from radioactive decay in two ways: it is not spontaneous, but is triggered by slow moving neutrons; and it releases huge amounts of energy.*



Nuclear Fission

However, waste heat (warms lake ecosystems), safety (nuclear melt-down), radioactive wastes (storage and contamination), economics (cost to build and maintain), and security (weapon grade plutonium) are all potential problems accompanying nuclear fission power reactors.



Nuclear Fission

NUCLEAR FISSION

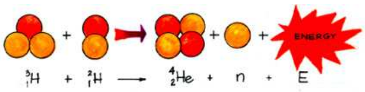
- reaction in which the large nucleus of an atom is split into smaller pieces (i.e. XY → X + Y + energy)
- very few emissions but many potential problems such as:
  - waste heat ☞ warms lake ecosystems
  - safety ☞ nuclear melt-down
  - radioactive wastes ☞ storage/contamination
  - economics ☞ cost to build and maintain
  - security ☞ weapon grade plutonium

NOTE!

Nuclear fission is the process used in our CANDU reactors. The liberated energy is converted into thermal energy which is then converted into electrical energy and waste heat, using a steam turbine.

Nuclear Fusion

A reaction in which two small atomic nuclei fuse together to form a larger more massive nucleus is known as ***nuclear fusion****. Not only is fusion the opposite of fission, it is potentially a much greater source of energy than fission and there are no dangerous waste products. The Sun uses nuclear fusion to provide us with energy.*



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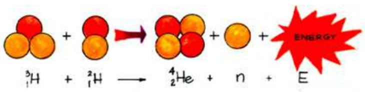
Nuclear Fusion

However, the only practical way to achieve fusion on a large scale is to heat the reactants to very high temperatures (~ 10^8 °C). The challenge then becomes how to confine the reactants that have been heated to a temperature and pressure comparable to that of the Sun's core. (At this temperature and pressure the reactants are a plasma!)



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Nuclear Fusion

NUCLEAR FUSION

- reaction in which two small atomic nuclei fuse together to form a larger nucleus (i.e. X + Y → XY + energy)
- potentially a much greater source of energy than fission and there are no dangerous emissions or waste products
- major problem is how to contain the plasma (i.e. the high-temperature/-pressure reactants)

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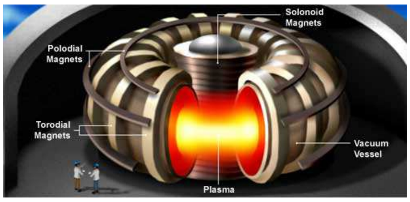
Nuclear Fusion

NOTE!
One of the most promising methods for controlling nuclear fusion is based on the principle of magnetic confinement. However, the cost has provoked controversy from skeptics who feel that too much money will be wasted with little return on investment.



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Mass-Energy Equivalence

In the early 20th century, Einstein proposed what is arguably the most famous equation in science:

$$E = mc^2$$

The equation challenged the foundations of physics by suggesting that energy and mass are equivalent. The equation states that the energy, E, of an object at rest is equal to its mass, m, multiplied by the speed of light, c, squared.

NOTE!
During a nuclear reaction, a small amount of mass disappears. This mass difference, called the ***mass defect****, is equivalent to the amount of energy released during the reaction.*

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Mass-Energy Equivalence

As Einstein's theory became widely accepted, the notions of conservation of mass and conservation of energy were replaced by the more general law of conservation of mass-energy:

Law of Conservation of Mass-Energy
Mass can transform into energy, and energy into mass, such that the total mass-energy in an isolated system remains constant.

NOTE!
An isolated system is a system that is free from outside influences. No energy flows into or out of the system, and no mass is added or removed from the system.

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Mass-Energy Equivalence

EINSTEIN'S EQUATION

$$E = mc^2$$

where E is the energy released (J)
m is the mass defect (kg)
c is the speed of light (3.00×10^8 m/s)

NOTE!
The atomic mass unit is commonly used in chemistry and physics as a more convenient unit of mass than the kilogram. One atomic mass unit (u) is equal to 1.66×10^{-27} kg.

Mass-Energy Equivalence

PRACTICE

1. What is the (i) mass defect and (ii) energy yield of the following fission reaction? Use the masses given below. (Recall: 1 u = 1.66×10^{-27} kg)

$${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{140}_{55}Cs + {}^{93}_{37}Rb + 3({}^{1}_{0}n) + \text{energy}$$

- mass of U = 235.044 u
- mass of Cs = 139.909 u
- mass of Rb = 92.922 u
- mass of neutron = 1.009 u

(i) mass defect = 0.195 u = 3.237×10^{-28} kg
(ii) E = 2.91×10^{-11} J

Mass-Energy Equivalence

PRACTICE

2. Determine the (i) mass defect and (ii) energy released from the following fusion reaction? (Recall: 1 u = 1.66×10^{-27} kg)

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

- mass of deuterium = 2.014 u
- mass of tritium = 3.016 u
- mass of He = 4.003 u
- mass of neutron = 1.009 u

(i) mass defect = 0.016 u = 2.658×10^{-29} kg
(ii) E = 2.39×10^{-12} J