Nuclear fission & fusion

Nucleon = proton or neutron
The binding energy per nucleon (i.e. the amount of energy per nucleon needed to separate a nucleus into nucleons far apart from each other) has a maximum for Iron (Fe):

![Graph showing binding energy per nucleon]

This means that Fe is the most stable (lowest potential energy) nucleus. We can get a lot of energy by combining light nuclei (e.g. H or He) into ones closer to Fe (fusion), and we can get quite a bit of energy by splitting heavy nuclei (e.g. $^{235}$U) into ones closer to Fe (fission).

Comparison of nuclear vs. coal for power generation

500MW power plant, 1 day of operation
Coal plant consumes 4.56 kg of coal (50 train car loads) & produces 1.77 kg of CO2.
Nuclear plant consumes 0.55 kg of $^{235}$U.
(The actual fuel used is $^{238}$U, with ~4% $^{235}$U content and the rest $^{238}$U. So, the amount of fuel used is actually ~15 kg.)
In either case, the mass of the end products is 0.59 less than the mass of the input products, due to the $E=mc^2$ of the energy produced.

Relating relativistic energy & momentum

on your next assignment, you'll show:

\[ E^2 = p^2c^2 + m^2c^4 \]
A result from stat. mech.:

The Equipartition Theorem:

For a system with \( k_B T \gg \) (quantum level spacing), each term in the total energy that is proportional to a velocity squared (e.g. \( \frac{1}{2} m \dot{v}_x^2 \) or \( \frac{1}{2} I \omega^2 \)) or to a position squared (e.g. \( \frac{1}{2} k x^2 \)) gets \( \frac{1}{2} k_B T \) of thermal energy.

As applied to the fundamental mode of a string:

This has kinetic & potential energy

\[ \Rightarrow \text{thermal energy} = 2 \cdot \frac{1}{2} k_B T = k_B T \]

Similarly, each of the higher modes (e.g. \( \frac{1}{2} k_B T \)) gets \( k_B T \).

The Ultraviolet catastrophe:

Cavity: a metal box:

The electric field component of the electromagnetic radiation is analogous to the string, & forms standing waves in the box:

Classical physics (i.e. equipartition theorem without the restriction \( k_B T \gg \) level spacing) predicts that each of these modes gets \( k_B T \)

\[ \Rightarrow \text{an } \infty \text{ amount of energy in the box!} \]