8.701

Introduction to Nuclear and Particle Physics

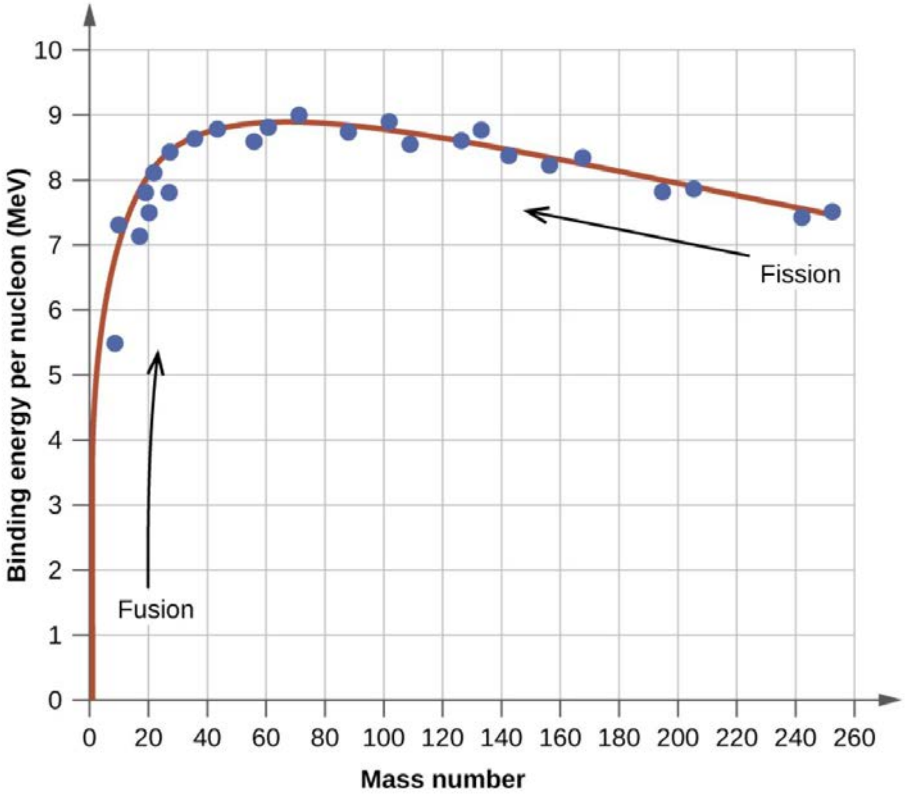
Markus Klute - MIT

9. Nuclear Physics

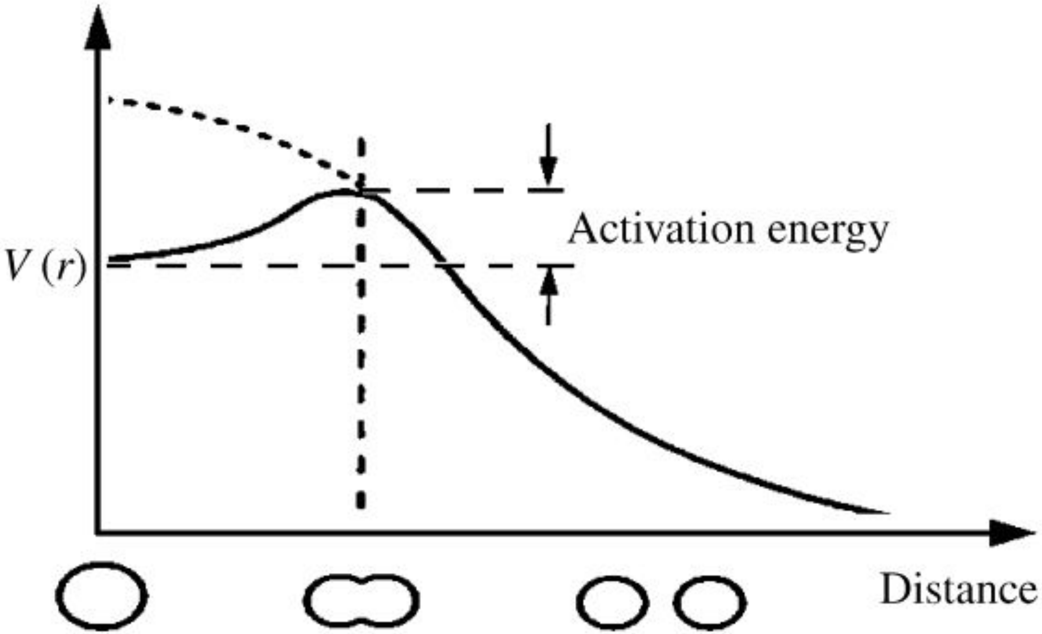
9.8 Fusion

Fusion

Energy production by two light nuclei fusing to produce a heavier more tightly bound nucleus.



Coulomb Barrier



Fusion

Practical way to overcome Coulomb barrier is to heat a confined mixture of nuclei to supply enough thermal energy.

Temperatures necessary can be estimated from E = kT. For 4.8 MeV this implies a temperature of 5.6×10^{10}K.

Typical temperature in stellar interior is 10^8K.

Quantum tunnelling and energy distribution allow natural fusion to occur.

Stellar Fusion

Energy dominantly produced via the proton-proton (PPI) cycle

Step 1: $^1\mathrm{H} + {}^1\mathrm{H} \rightarrow {}^2\mathrm{H} + e^+ + \nu_e + 0.42\,\mathrm{MeV}$

Step 2: $^1\mathrm{H} + {}^2\mathrm{H} \rightarrow {}^3\mathrm{He} + \gamma + 5.49\,\mathrm{MeV}$

Step 3: $^3\mathrm{He} + {}^3\mathrm{He} \rightarrow {}^4\mathrm{He} + 2({}^1\mathrm{H}) + 12.86\,\mathrm{MeV}$

Combined: $4({}^1\mathrm{H}) \rightarrow {}^4\mathrm{He} + 2e^+ + 2\nu_e + 2\gamma + 24.68\,\mathrm{MeV}$

Stellar Fusion

Also interesting is the carbon cycle (CNO chain).
Contributes about 3% of the sun's energy output.

$$^{12}C + {}^{1}H \rightarrow {}^{13}N + \gamma + 1.95\text{ MeV}$$

$$^{13}N \rightarrow {}^{13}C + e^{+} + \nu_e + 1.20\text{ MeV}$$

$$^{13}C + {}^{1}H \rightarrow {}^{14}N + \gamma + 7.55\text{ MeV}$$

$$^{14}N + {}^{1}H \rightarrow {}^{15}O + \gamma + 7.34\text{ MeV}$$

$$^{15}O \rightarrow {}^{15}N + e^{+} + \nu_e + 1.68\text{ MeV}$$

$$^{15}N + {}^{1}H \rightarrow {}^{12}C + {}^{4}He + 4.96\text{ MeV}$$

Combined:

$$4\,({}^{1}H) \rightarrow {}^{4}He + 2e^{+} + 2\nu_e + 3\gamma + 24.68\text{ MeV}$$

Fusion Reactors

Several efforts on the way to achieve controlled fusion in the laboratory. Pp reaction are to slow but deuterium and tritium are promising

$$^{2}_{1}\mathrm{H} + ^{2}_{1}\mathrm{H} \rightarrow ^{3}_{2}\mathrm{H} + n + 3.27\ \mathrm{MeV}$$

$$^{2}_{1}\mathrm{H} + ^{3}_{1}\mathrm{H} \rightarrow ^{4}_{2}\mathrm{He} + n + 17.62\ \mathrm{MeV}$$

$$^{2}_{1}\mathrm{H} + ^{2}_{1}\mathrm{H} \rightarrow ^{3}_{1}\mathrm{H} + p + 4.03\ \mathrm{MeV}$$

Deuterium-tritium reaction has advantage over deuterium-deuterium as the cross section is much higher.

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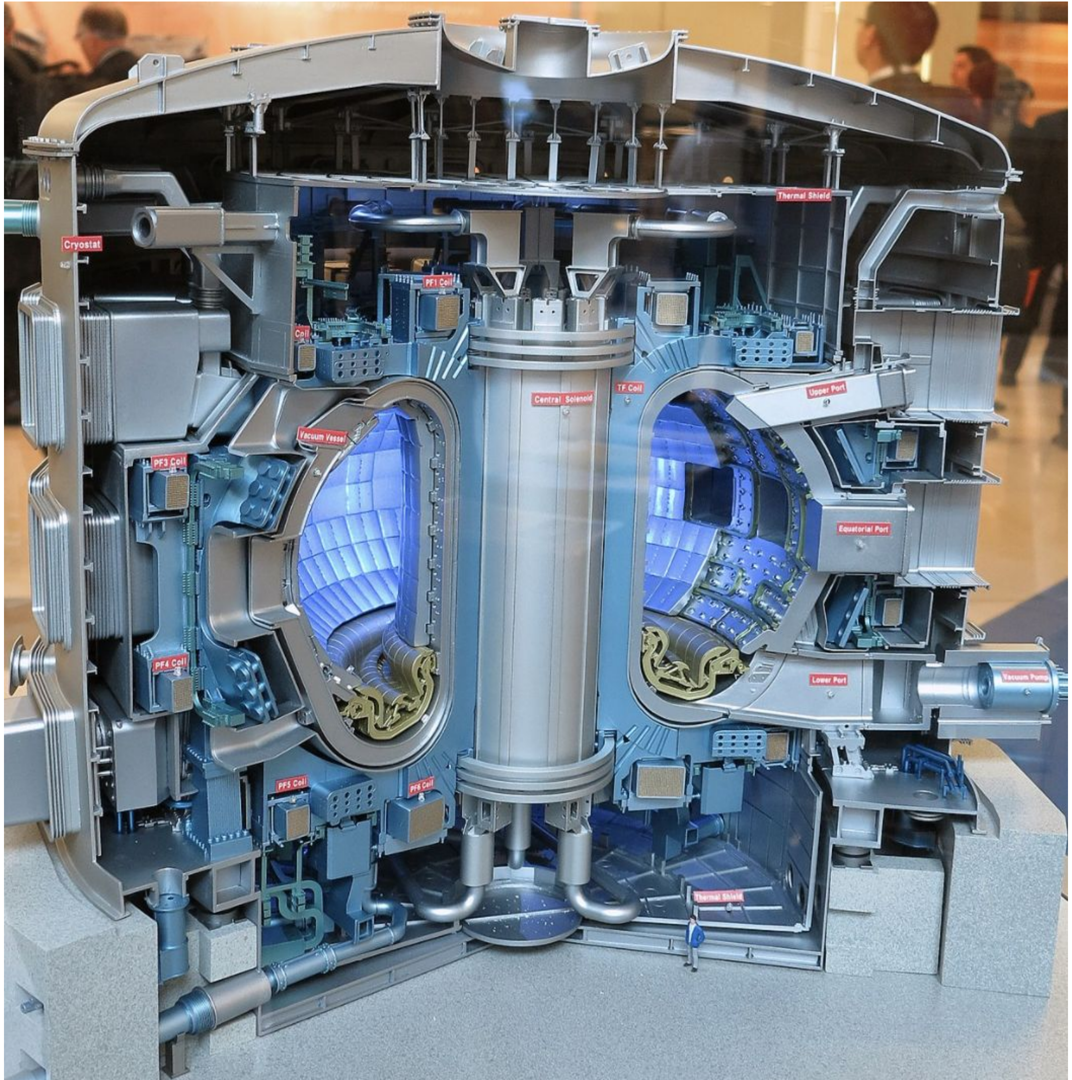
Thermal Shield
Cryostat
PF1 Coil
Coil
Central Solenoid
TF Coil
Upper Port
Vacuum Vessel
PF3 Coil
Equatorial Port
PF4 Coil
Lower Port
Vacuum Pump
PF5 Coil
PF6 Coil
Thermal Shield

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