Nuclear Fusion and Radiation

Midterm 1 - Content (Meetings 1-12)

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Lecture 1

- Relativistic energy conservation in nuclear reactions
- Computation of energy release Q
  - Mass
  - Binding energy
- Unit definition (amu (mass), eV (energy))
- Computation of $Q = 17.6$ MeV for DT fusion reaction
- Fusion vs. Fission based on B/A
- Fusion vs. Fission based on energy per gram of fuel
- Discussion on mismatch between estimated electrostatic potential energy and energy for maximum probability of DT fusion reaction

Lecture 2

- Modern physics concepts
- Theory of special relativity
  - Lorentz transformation
  - Proper vs. apparent time, length, and mass.
  - Relativistic energy and momentum
- Wave-particle duality
  - Photoelectric Effect
  - Compton Scattering
  - Electron Scattering
- Quantum mechanics
- Explanation on mismatch between estimated electrostatic potential energy and energy for maximum probability of DT fusion reaction

Lecture 3

- Fuel cycle for DT fusion reaction
- Coulomb scattering as competing process for fusion
- Important definitions
  - Cross section
  - Probability of reaction per unit length traveled
  - Reaction rate
- Fusion gain in ideal fusion reactor
  - Accelerator: energetic deuterium beam on cold tritium target
  - Gain too high when Coulomb scattering neglected
  - Approximate formula for scattering cross section
  - Gain still too high when $D - T^{cold}$ scattering considered even for $s = 1$ (s is the number of Coulomb scattering collisions required for the deuteron energy to be below fusion requirements)

Lecture 4

- Fusion gain in ideal (accelerator: energetic deuterium beam on cold tritium target) fusion reactor
  - Estimated $s \neq 1$ for D–T^{cold} scattering. Higher gain.
  - Estimation of s for $D - e^{cold}$ scattering. Gain now drops below 1!!! What can we do?
  - Heating up the tritium target seems to produce reactor-grade gains.
- We abandon the ideal reactor concept $\rightarrow$ PLASMA
- Maxwell-Boltzmann distribution. "Maxwellian" averages.
  - $< E >$, $< v >$, $< \sigma v > \rightarrow$ Reaction Rate
- Important definitions
  - Reaction mean life, Reaction mean free path
  - Power density (DT), pressure density, energy density

Lecture 5

- Power balance
  - $P_{aux} + P_\alpha = P_L$(conduction+diffusion) $+ P_b$(radiation)
  - $P_\alpha = n_D n_T < \sigma v > E_\alpha$
  - $P_L = (3nkT/2)/\tau_E$, $P_b = C T_e^{1/2} n_e^2 Z_{eff}$
- Charge neutrality: $n_e = n_p$
- Total density: $n = n_e + n_i = n_e + \sum_j n_{ion}^j$
- Common fueling assumption: $n_D = n_T$
- Effective atomic number: $Z_{eff} = \sum_j n_{ion}^j < \bar{Z}_j >^2 / n_e$
- Important metrics
  - Power gain $Q = P_f / P_{aux}$ (DT plasmas: $P_f = 5P_\alpha$)
  - Lawson criterion for ignition $n_e \tau_E$
- Particle balance