What is Nuclear Fusion?
Energy is released when light nuclei fuse to form heavier nuclei. This is the energy which powers stars such as the Sun. The amount of energy released is related to the difference in the masses of the initial and final nuclei according to $E = mc^2$.

Nuclear forces are of short range. Hence reactions occur only when nuclei are in close proximity and to achieve this they must have energy sufficient to overcome their repulsive electrostatic forces. This requires such high temperatures as 15,000,000 K as in the Sun.

Challenges and objectives
- Achieve temperatures such as that in the Sun’s interior;
- Confining reacting species long enough for fusion reactions to occur;
- Achieve energy break-even: output energy compensates input energy.

Two Major Approaches to Fusion
- Magnetic confinement: A low density plasma of H+ ions is confined by magnetic fields.
- Inertial confinement: A pellet of solid H is bombarded by high-intensity lasers.

Primary reactions:
- $D + D \rightarrow T + p + 4.03\, \text{MeV}$;
- $D + D \rightarrow ^3\text{He} + n + 3.27\, \text{MeV}$

Secondary reactions:
- $D + T \rightarrow \alpha + n + 17.8\, \text{MeV}$;
- $D + ^3\text{He} \rightarrow \alpha + p + 18.3\, \text{MeV}$

Fusion reaction rates proportional to $n^2$.

$n = \text{particle density}$.

Magnetic confinement methods: $\approx 10^{15}\, \text{cm}^3 \Rightarrow T = 10^8\, \text{K}$

Proposed Method
Exploit $n^2$ factor under reduced degrees of freedom
Perform under adiabatic conditions
⇒ appreciable fusion rates at lower T

Mechanical adiabatic compression

Dense gas of $D_2$ undergoes adiabatic compression
Rapid process - explosively driven
Well-insulated chamber ⇒ retain energy internally

Starting conditions:
- One molecule $D_2$ at atmospheric pressure and room temperature.
- Apply compression. Compression factor $\beta = V_f / V$. T increases.

Assumptions:
- Reversible adiabatic compression
- Apply equilibrium thermodynamics
- Treat as van der Waals (vdW) gas: $(P + a n^2 / V^3)(V - Nb) = RT$

$\beta = \frac{1}{3}$

$\gamma = \text{specific heat ratio}$

Related to number of degrees of freedom $f$ of the gas: $\gamma = (f + 2) / f$

For monatomic gas: $f = 3$

Deprive particles of freedom of motion ⇒ larger T increase for given energy input. Accomplish with
1. External magnetic field(s)
2. Electric discharge in direction of piston motion. Also $\Rightarrow$ Pinch Effect.

Adiabatic compression of a vDW gas

$T = T_0 \left( \frac{V_0 - Nb}{V - Nb} \right)^{\gamma - 1} = T_0 \left( \frac{\beta (V_0 - Nb)}{V - \beta Nb} \right)^{2/\gamma}$

Work to compress a van der Waals gas

$W = - \int \left( \frac{NRT}{2} \left( \frac{\beta (V_0 - Nb)}{V - \beta Nb} \right)^{2/\gamma} - \beta^{2/\gamma} \right) - \frac{a N^2}{V^3} \text{d}V$

Energy release

$\sigma = \text{reaction cross section}$
$v = \text{relative velocity of interacting nuclei}$

Energy release in time $\Delta t$:
$\Delta E = \sigma Q \, V \, \Delta t$, $V = \text{final volume}$

$Q = \text{avg energy release/reaction. Previously considered fusion to occur only at end of compression. Present work computes T and $\Delta E$ at various stages of the compression.}

Multistage data for vDW gas

Consider only D+D: Avg $Q = 3.65\, \text{MeV}$

Calculate final $T$ and $\Delta E / W$ as function of total no. of stages S.

Total $\Delta t = 0.001\, \text{sec}$.

$T$ and $\Delta E / W$ vary directly with S.

Applications
- Single shot: Neutron source to initiate fission.
  Multiple compressions in dual chambers.

Summary and conclusions
- Exploited $n^2$ factor and reduced degrees of freedom.
  Adiabatic conditions $\Rightarrow$ energy retained internally.
  Found some favorable cases.
  To be more realistic:
  - Not all input energy serves to compress gas.
  - Consider particle losses via leakage.
  - Compensated by ignoring:
    D-T reactions; Pinch Effect.
  - Enhancements: Deuterated walls; Screening effects of electrons.