Combustion Physics

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Summer School on Combustion

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What is Combustion?

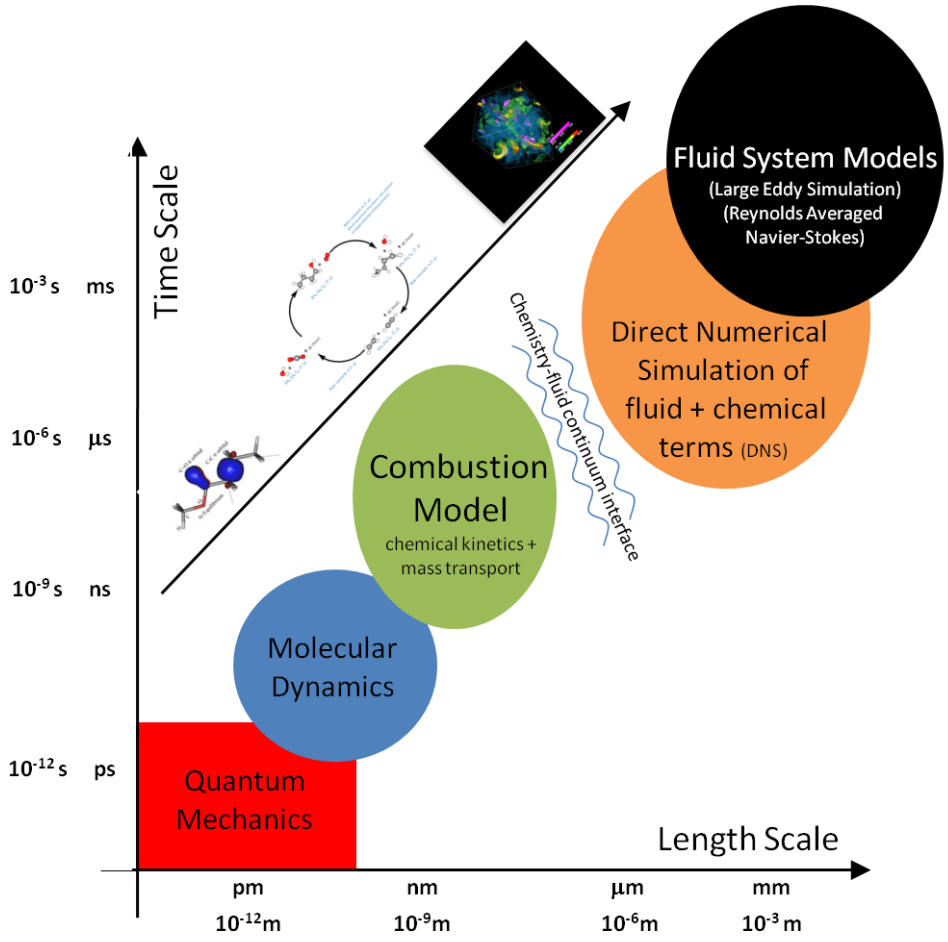
- Study of chemically reacting flows with highly exothermic, temperature-sensitive reactions

A Laminar Bunsen Flame

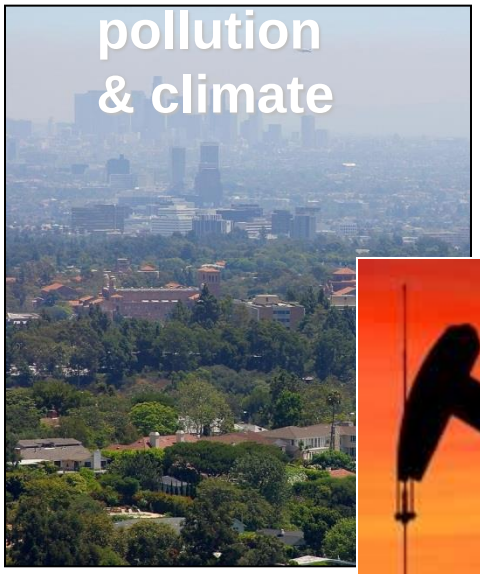
A Turbulent Jet Flame

Combustion is A Multi-physics & Multi-scale Science

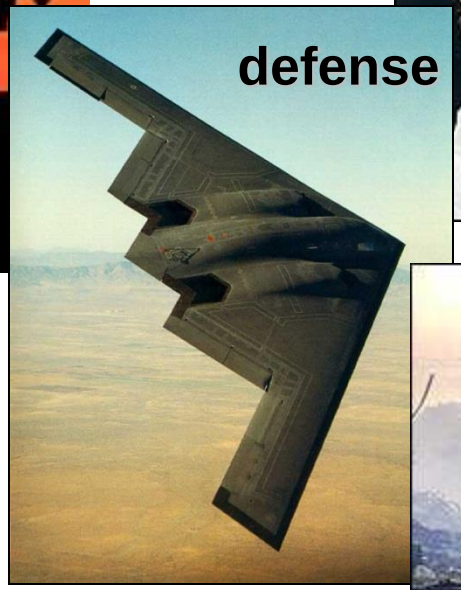
- Combustion is a multi-physics science, embodying two major branches of nonlinear science:
  - Chemical kinetics
  - Fluid mechanics
- Combustion is a multi-scale science
  - Electronic and inter-/intra-molecular interactions
  - Molecular rearrangement
  - Nano-particulate formation (e.g. soot)
  - Turbulent fuel/air mixing



Combustion is
A Major Technology Driver

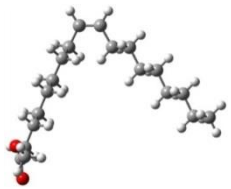


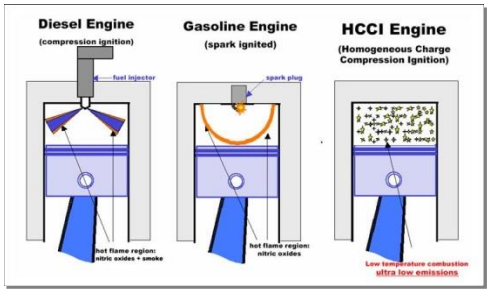
materials
synthesis



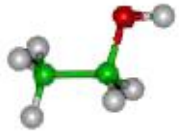
Role of Combustion in An Energy-Constrained World

- Burning of fossil fuels constitutes ~85% of the world's energy needs, negatively impacts
  - Energy sustainability
  - Energy security
  - Climate change

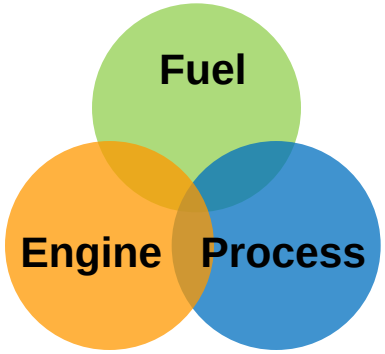




- In response, energy infrastructure is changing
  - Fuels: heavy hydrocarbons (coal, oil shale, tar sand…); Renewable biofuels (alcohols, biodiesel…)
  - Engines: New concepts (direct injection, HCCI, low temperature…)



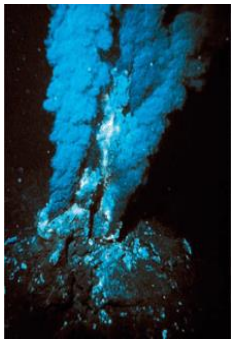
- Combustion-enabled solutions
  - Improve combustion efficiency & emissions
  - Use synfuels & carbon-neutral biofuels
  - (Co-)design/develop new fuels & engines

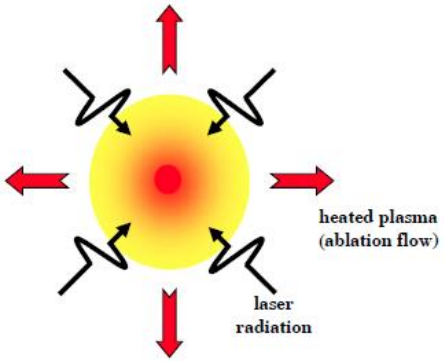


New Frontiers of Combustion

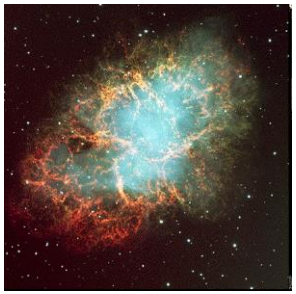
- Study of ~~chemically~~ **reacting flows**
- Transdisciplinary:

Biological science: health; cellular transport & reactions; network analysis of biological processes; origin of life from ocean thermal vents

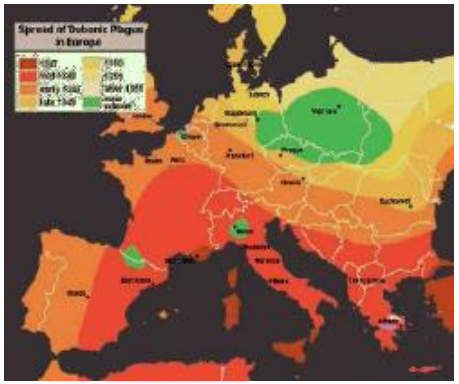




Nuclear science: nuclear reactions; hydrodynamic front instability in inertial confinement fusion



Astrophysics: origin of universe; supernova



Societal science: social network; traffic network; spreading of disease fronts (bubonic plaque in 14th century)

Course Content

Topics of Daily Lectures

- Day 1: Chemical thermodynamics and kinetics
- Day 2: Generalized formulations
- Day 3: Diffusion flames and heterogeneous combustion
- Day 4: Laminar premixed flames
- Day 5: Combustion in complex flows

Day 1: Chemical Thermodynamics and Kinetics

1. **Chemical Thermodynamics**
   - Chemical equilibrium
   - Energy conservation & adiabatic flame temp., T_{ad}
2. **Chemical Kinetics**
   - Reaction rates and approximations
   - Theories of reaction rates
   - Straight and branched chain reactions
3. **Oxidation Mechanisms of Fuels**
   - Hydrogen, CO, hydrocarbons

Day 2: Generalized Formulations

1. **Conservation Equations**
    1. Derivation and constitutive relations
    2. Simplified diffusion-controlled system
    3. Conserved scalar formulations
2. **Discontinuity Surface Formulations**
    1. Generalized reaction-sheet formulation
    2. Reaction-sheet analysis of diffusion flames
    3. Rankine-Hugoniot waves in premixtures

Day 3: Diffusion Flames and Heterogeneous Combustion

1. **Burke-Schumann and counterflow flames**
2. **Heat & mass transfer with condensed fuels**
3. **Droplet combustion**
    1. The d^2-Law
    2. Multicomponent fuels
4. **Other heterogeneous systems**
    1. Carbon and metal particles
    2. Spray flame

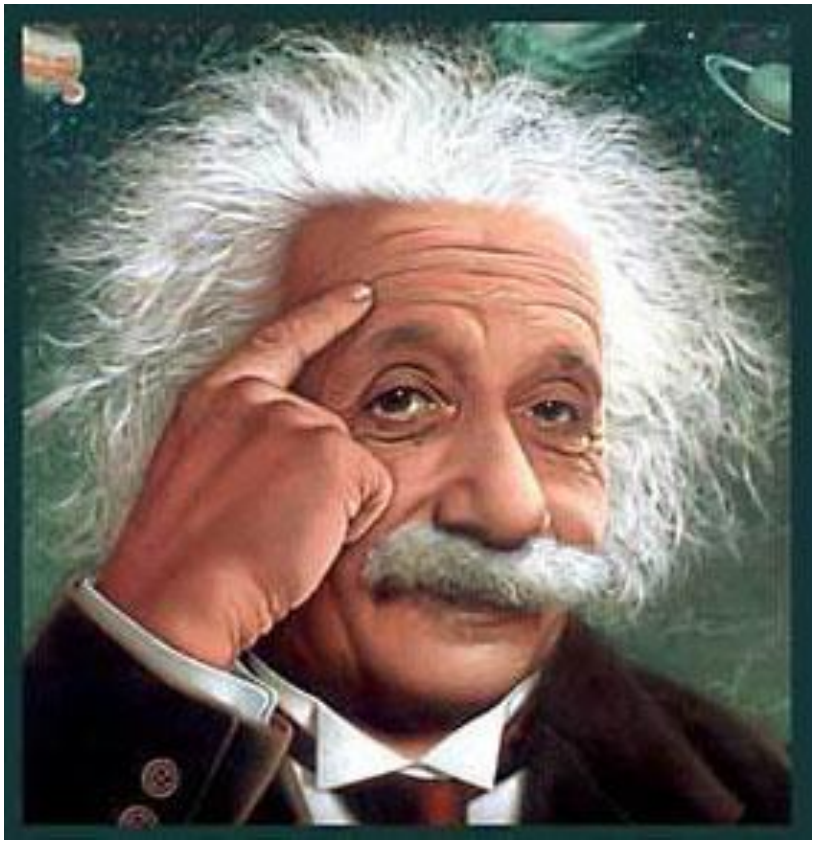
Day 4: Laminar Premixed Flames

1. **The standard premixed flame**
    1. Phenomenological and asymptotic solutions
    2. Parametric dependence
    3. Chemical structure
2. **Limit phenomena**
    1. The S-curve concept
    2. Extinction through volumetric heat loss
3. **Aerodynamics of flames**
    1. Hydrodynamic stretch
    2. Flame stretch
    3. Flamefront instabilities

Day 5: Combustion in Complex Flows

1. **Turbulent flows**
    1. General concepts of turbulent flows
    2. Simulation and modeling
    3. Premixed burning: regime diagram and burning velocities
2. **Boundary-layer flows**
    1. Consideration of similarity
    2. Diffusion flame in the ablating Blasius flow
    3. Ignition in the Blasius flow
    4. Stabilization of the jet flame
3. **Supersonic flows**
    1. Sound waves in reactive flows
    2. Structure of detonation waves
    3. Direct and indirect detonation initiation

Overarching Messages of the Course:
Expand the Mind!



Overarching Messages of the Course:

Appreciate the Beauty!

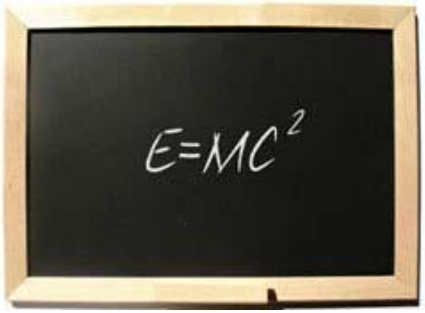
- Beauty is the driving force of the human intellect
- Unification is the ultimate goal of the scientific pursuit

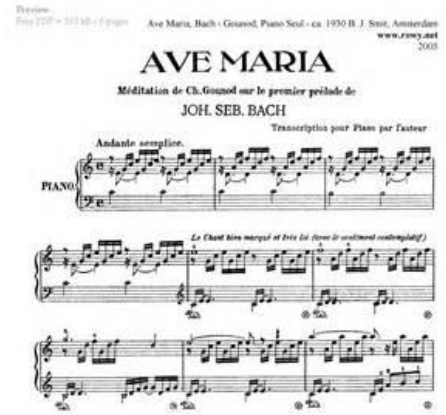
$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

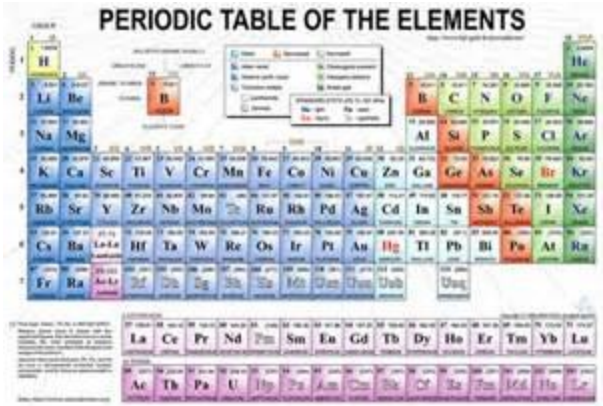
$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$







Unified concepts and theories are inevitably beautiful

Course Commences!!