
Acknowledgements: SunRISE and SunRISE GRL were sponsored by NASA grant #AWDo06989, and hosted at the Climate and Space Sciences and Engineering (CLaSP), University of Michigan College of Engineering, Ann Arbor, MI. Radio JOVE receives funding from NASA Citizen Science Seed funding program (NNH21ZDA001N-CSSFP), Grant# 80NSSC23K0.
Prerequisites for Training Modules

1. High School Reading Comprehension and General Science
2. Basic Geometry
3. Electromagnetic Spectrum
4. Speed, Wavelength, Frequency, and Energy of Waves
5. Graphical Interpretation of Data
6. Training Module 0.0
Learning Objectives

1. The structure of the Sun
2. Solar interior layers and processes
3. Nuclear reactions that power the Sun
4. Energy transport mechanisms
Sun - Structure

Structure

1. Interior
   a. Core
   b. Radiative Zone
   c. Convection Zone
2. “Surface”
   a. Photosphere
3. Atmosphere
   a. Chromosphere
   b. Transition Zone
   c. Corona
Sun Interior

Interior

a. Core – Nuclear Reactions
b. Radiative Zone – energy transport
c. Convection Zone – energy transport
d. Force Balance
   Outward Pressure vs. Inward Gravity (keeps it stable)

Interior Density = 150 g/cm³
Photosphere Density = 0.0000002 g/cm³
Average = 1.4 g/cm³
Nuclear Fusion

Basic Reaction: \(4H \rightarrow \text{He} + \text{Energy!}\)

Net Reaction:
\[4H \rightarrow \text{He} + 2e^+ + 2\gamma + 2\nu\]
\[4H \rightarrow \text{He} + 7\gamma + 2\nu\]

Requirements: High Temperature, High Pressure
Sun’s Core: 15 million K
100-200 billion atmospheres!

\(e^+ = \text{positron}\)
\(\gamma = \text{gamma ray}\)
\(\nu = \text{neutrino}\)
Proton-Proton Chain Timescales

Net Reaction
\[ 4H \rightarrow \text{He} + 7\gamma + 2\nu \]
Nuclear Energy

Energy from the Nuclear “furnace”

4H $\rightarrow$ He + neutrinos + Energy

Mass of 4 H atoms = 6.693 x 10^{-27} kg
- Mass of He atom = 6.645 x 10^{-27} kg
  Mass Lost = 0.048 x 10^{-27} kg

E = mc^2
  = (0.048 x 10^{-27} kg) x (3 x 10^8 m/s)^2
Energy = 4.3 x 10^{-12} Joules

Basic Reaction 4H $\rightarrow$ He + Energy!

600 million metric tons of Hydrogen are converted into Helium EACH second inside the Sun!!!
Stellar Structure
A peek inside a star!
Radiation and Convection Zones

Energy from the core is transported through the radiation zone by a random walk of photons as they are absorbed and emitted. The overall “flow” of energy is outward.

As the temperature decreases outward convection becomes the more efficient mode of energy transport.

Credit: http://www.solarsystemcentral.com/
Photosphere

Photosphere Granulation – bubbles of gas rising and sinking near the surface caused by convection

27x27 Mm² field, 35 minutes

Credit: Patrick Hall, York University

SOHO, NASA & ESA
Resources

NASA Marshall Space Flight Center Solar Physics
https://solarscience.msfc.nasa.gov/

NASA Solar and Heliospheric Observatory (SOHO)
https://soho.nascom.nasa.gov/home.html

NOAA Space Weather Prediction Center
https://www.swpc.noaa.gov/

Australian Space Weather Forecasting Center
https://www.sws.bom.gov.au/Educational/2/1

Space weather:
https://spaceweather.com/
https://swe.ssa.esa.int/current-space-weather
https://www.swpc.noaa.gov/