

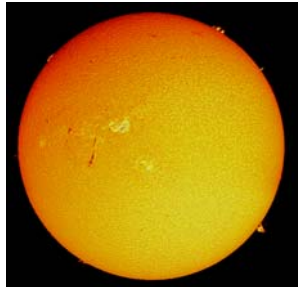
Chapter 15

The Sun: A Nuclear Powerhouse

14.1 The Visible Sun

What is the Sun?

- The Sun is a star
- Enormous ball of extremely hot gas shining under its own power
- Large enough to hold about 1.3 million Earths
- Distance from Earth: 93 million miles



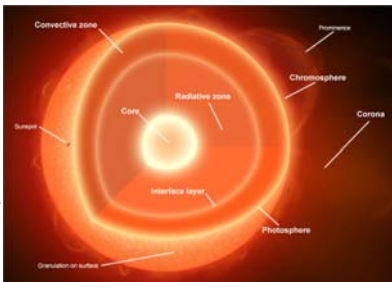
14.1 The Visible Sun

Three outer layers

- Photosphere: visible surface
- Chromosphere: tenuous outer layer, red
- Corona: atmosphere

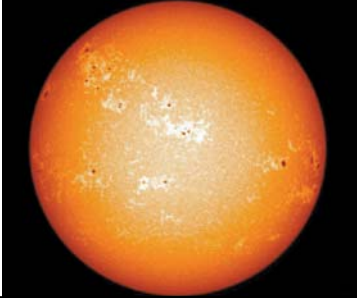
Three inner layers

- Core
- Radiative Zone
- Convective Zone



15.1 Thermal and Gravitational Energy

- We know that the Sun radiates heat. **Why is the Sun hot?**




15.1 Thermal and Gravitational Energy

- We know that the Sun radiates heat. **Why is the Sun hot?**
 - 19th century scientists knew of two possible sources for the Sun's energy
 - heat, or *thermal energy*
 - *gravitational energy*

15.1 Thermal and Gravitational Energy

Thermal energy

- Generated with source of fuel is burned 
 - wood
 - coal
 - gasoline
- We know exactly how much energy each fuel would produce, and the Sun produces *much* more.
- Even if the Sun were made of a combustible fuel, it would last only a few thousand years before fuel would be depleted.

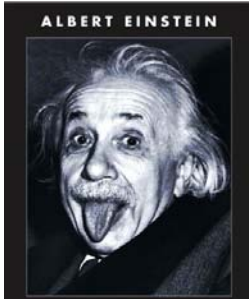
15.1 Thermal and Gravitational Energy

Gravitational energy

- Gravity converts into heat
- How?
- Kelvin and von Helmholtz: Thought that the Sun's outer layers might be falling inward because of gravity
 - They calculated that if the Sun were shrinking at a rate of 40 meters/year, it would produce the energy output that we see today
 - Energy output would remain stable for about 100 million years
- But rocks found on Earth and Moon date back *billions* of years

15.2 Mass, Energy, and the Theory of Relativity

The true source of Sun's energy not identified until 20th century, when along came...



15.2 Mass, Energy, and the Theory of Relativity

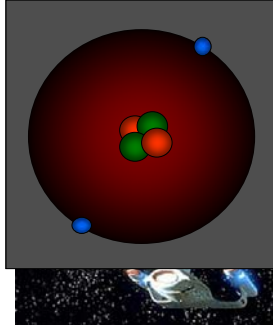
Energy $E = mc^2$ mass speed of light squared

- Conversion formula, similar to inches = feet x 12
- Mass does not have to be traveling at the speed of light for this to apply
- 1 gram of matter would equal energy of 15,000 barrels of oil by combustion
- Problem: Does not tell how mass is converted into energy, just how much energy will result
- To understand how, we first need to understand...

15.2 Mass, Energy, and the Theory of Relativity

Elementary particles (atoms)

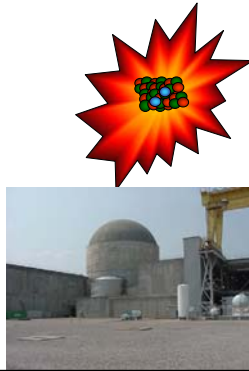
- You know about:
 - Protons (+ charge)
 - Electrons (- charge)
 - Neutrons (no charge)
- All held together by very powerful force called *strong nuclear force*
- But what about:
 - Positrons (“antimatter”)
 - Neutrinos (“little neutral ones”)



15.2 Mass, Energy, and the Theory of Relativity

Nuclear energy: Fission

- Energy released when a larger atomic nucleus breaks into two smaller components.
- Example: Uranium breaks into barium and krypton when a neutron smashes into it, emitting gamma radiation in the process.
 - A pound of highly enriched uranium is equal to a million gallons of gasoline.
- Nuclear power plants



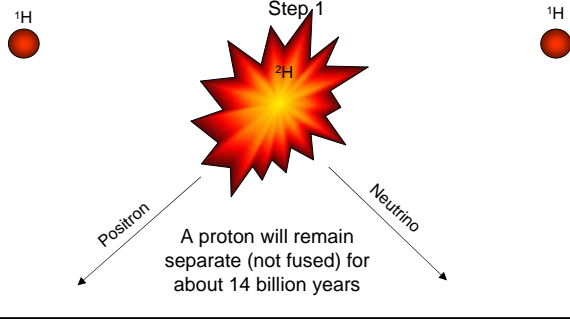
15.2 Mass, Energy, and the Theory of Relativity

Nuclear energy: Fusion

- When two lighter atomic nuclei come together to form a heavier one, energy is released
- BUT like forces repel, so how can two nuclei come together?
- Answer: lots of heat!!
- Two protons can fuse only @ temps > 10 million K and speeds > 1,000 km/s (2 million mph)
- Where? In the core of stars!

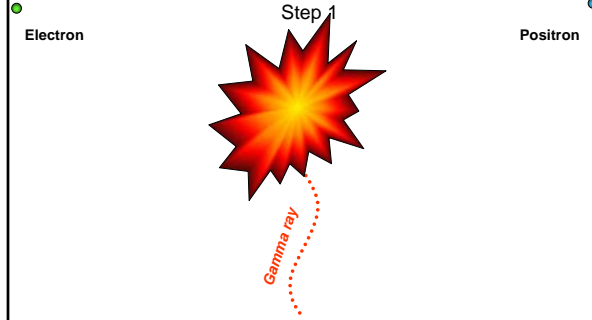
15.2 Mass, Energy, and the Theory of Relativity

Nuclear Reactions in the Sun's Interior: Proton-Proton Chain



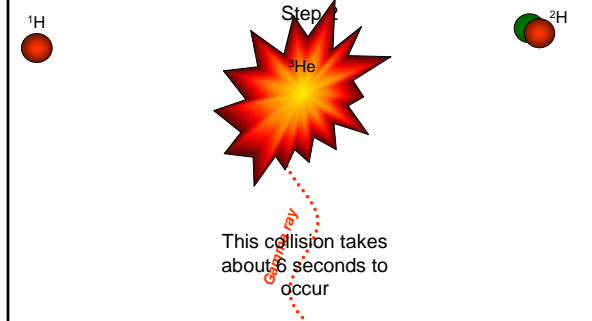
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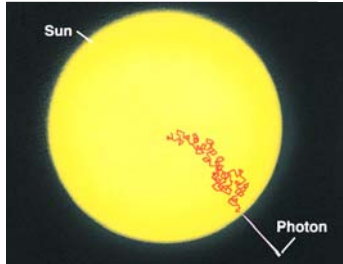
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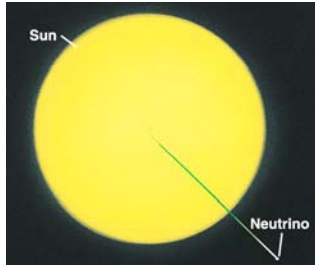
Nuclear Reactions in the Sun's Interior: Proton-Proton Chain



The trip to the edge of the Sun for a gamma ray takes about one million years, lowering its energy level along the way.

15.2 Mass, Energy, and the Theory of Relativity

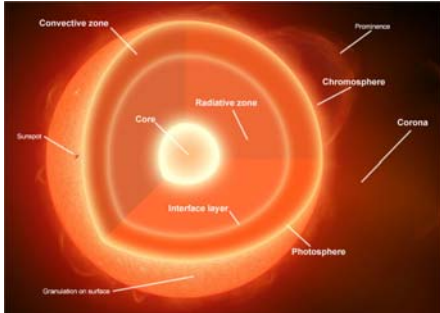
Nuclear Reactions in the Sun's Interior: Proton-Proton Chain



The trip to edge of the Sun for a neutrino takes about two seconds!

15.3 Interior of the Sun: Theory

- The Sun is a Gas (okay, technically *Plasma*)
 - So hot that everything remains gaseous throughout



15.3 Interior of the Sun: Theory

- The Sun is Stable
 - Hydrostatic equilibrium
 - Fancy way of saying that the Sun is neither expanding nor contracting
 - Internal regions within Sun tend to collapse the Sun
 - To balance, pressure @ core must be extremely high, indicating temp @ core must equal 15 million K
 - If internal pressure were greater, Sun would expand
 - If less, Sun would contract



15.3 Interior of the Sun: Theory

- The Sun is not Cooling Down
 - As energy flows from core to outer edge, it is replaced by more heat from subsequent fusion reactions.

15.3 Interior of the Sun: Theory

Heat Transfer

– Energy transfers in one of three ways:

- Radiation: photons move away from hot material and absorbed by cooler material.
 - Example: Heating element on electric stove
- Conduction: atoms or molecules pass their energy by colliding with other atoms of molecules.
 - Example: Warm handle on metal spoon in a hot cup of coffee
- Convection: currents of warm material rise and carry their heat to cooler layers.
 - Example: Boiling water

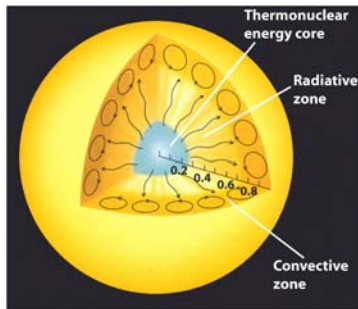
15.3 Interior of the Sun: Theory

Heat Transfer in a Star

– Energy still transfers in the same ways

– Energy @ core: fusion

- Only 1/4 of diameter
- Contains 1/3 of mass
- Density = 150x water



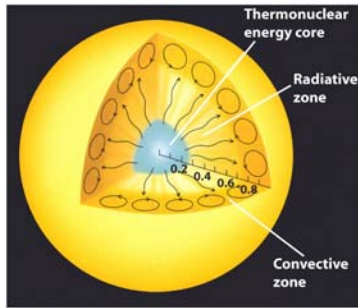
15.3 Interior of the Sun: Theory

Heat Transfer in a Star

– Energy transferred outward by radiation

- To about 75% of the diameter

– Convection takes it the rest of the way



15.4 The Solar Interior: Observations

- Neutrinos
 - Created during nuclear fusion at Sun's core
 - Travel at nearly the speed of light, 186,000 miles per second
 - To neutrinos, the Sun and the Earth are transparent
 - How can we detect them?
 - By interactions with other atoms
 - Dry-cleaning fluid (C_2Cl_4) seems especially sensitive, as neutrinos turn radioactive argon.
 - But interactions is so rare that a LOT of cleaning fluid is needed.

15.4 The Solar Interior: Observations

- Neutrinos
 - To detect solar neutrinos, in 1970, Brookhaven National Laboratory's Ray Davis and colleagues placed a 400,000-liter tank of cleaning fluid down in a gold mine in Lead, South Dakota.
 - Mine used to shield sensitive detectors from cosmic rays.
 - Results showed that there are only about 30% as many solar neutrinos as was originally predicted.
 - Later experiments showed that 70% of neutrinos undergo changes, indicating that they have a mass.
