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ASTRONOMY

Chapter 16 THE SUN: A NUCLEAR POWERHOUSE

PowerPoint Image Slideshow

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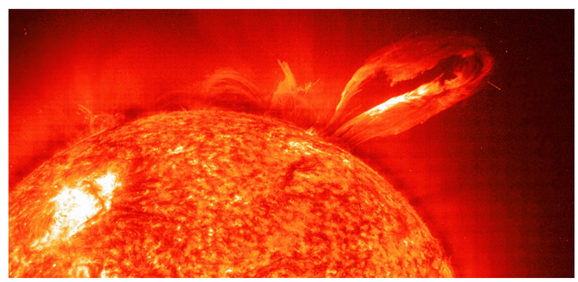
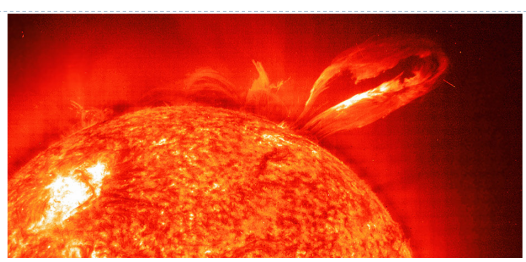
16.1 THE SOURCE OF SUNSHINE

- **The Sun.** It takes an incredible amount of energy for the Sun to shine, as it has and will continue to do for billions of years.

Why does the Sun shine?

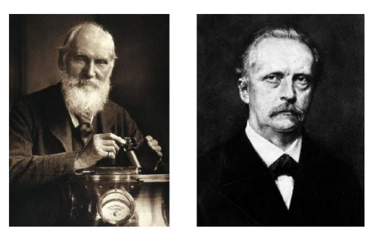




Is it on FIRE?

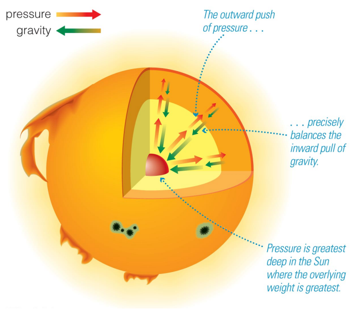
$$\frac{\text{Chemical Energy Content}}{\text{Luminosity}} \sim 10{,}000 \text{ years}$$

Figure 16.2



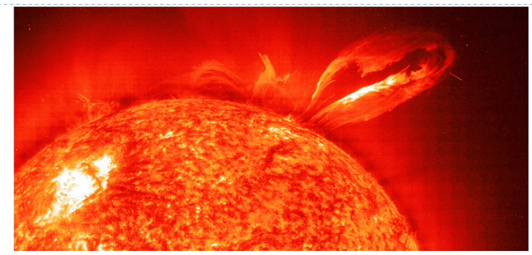
(a) (b)

- **Kelvin (1824–1907) and Helmholtz (1821–1894).** (a) British physicist William Thomson (Lord Kelvin) and (b) German scientist Hermann von Helmholtz proposed that the contraction of the Sun under its own gravity might account for its energy.



Gravitational contraction… provided energy that heated the core as the Sun was forming.

Contraction stopped when fusion started replacing the energy radiated into space.

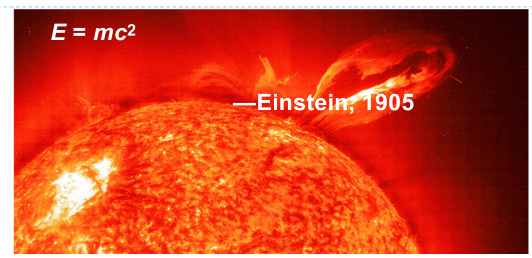


Is it CONTRACTING?

$$\frac{\text{Gravitational Potential Energy}}{\text{Luminosity}} \sim 25 \text{ million years}$$

16.2 MASS AND ENERGY

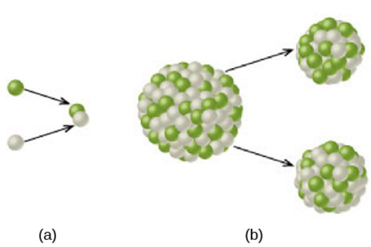
- **Albert Einstein (1879–1955).** This portrait of Einstein was taken in 1912. (credit: modification of work by J. F. Langhans)



It is powered by NUCLEAR ENERGY!

$$\frac{\text{Nuclear Potential Energy (core)}}{\text{Luminosity}} \sim 10 \text{ billion years}$$

Converting mass into energy

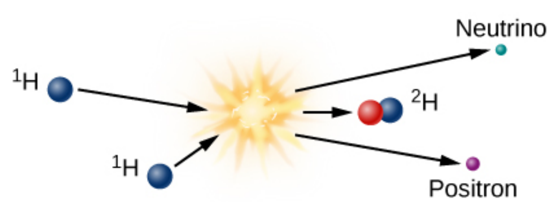


- **Fusion and Fission.**

(a) In fusion, light atomic nuclei join together to form a heavier nuclei, releasing energy in the process. (Sun,Stars)

(b) In fission, energy is produced by the breaking up of heavy, complex nuclei into lighter ones. (Nuclear power plants)

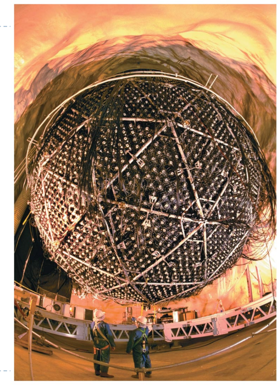
Figure 16.6



- **Proton-Proton Chain, Step 1.** This is the first step in the process of fusing hydrogen into helium in the Sun. High temperatures are required because this reaction starts with two hydrogen nuclei, which are protons (shown in blue at left) that must overcome electrical repulsion to combine, forming a hydrogen nucleus with a proton and a neutron (shown in red). Note that hydrogen containing one proton and one neutron is given its own name: deuterium. Also produced in this reaction are a positron, which is an antielectron, and an elusive particle named the neutrino.

Figure 16.4

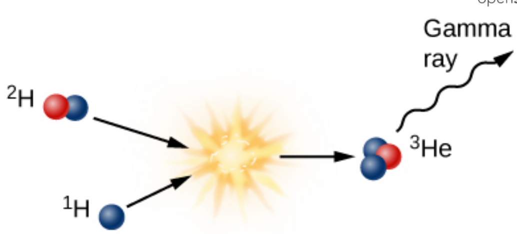
- **Wolfgang Pauli in 1945.** Pauli is considered the "father" of the neutrino, having conceived of it in 1933.



Solar neutrino problem:
Early searches for solar neutrinos failed to find the predicted number.

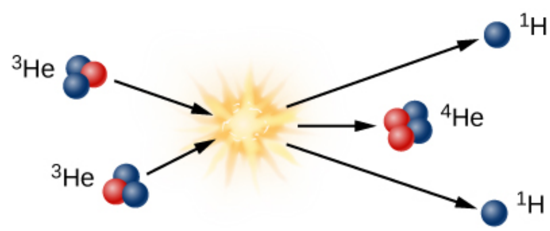
More recent observations find the right number of neutrinos, but some have changed form.

Figure 16.7



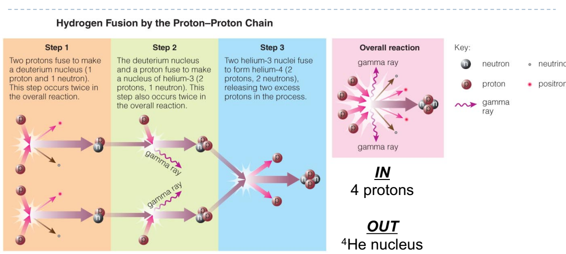
- **Proton-Proton Chain, Step 2.** This is the second step of the proton-proton chain, the fusion reaction that converts hydrogen into helium in the Sun. This step combines one hydrogen nucleus, which is a proton (shown in blue), with the deuterium nucleus from the previous step (shown as a red and blue particle). The product of this is an isotope of helium with two protons (blue) and one neutron (red) and energy in the form of gamma-ray radiation.

Figure 16.8



- **Proton-Proton Chain, Step 3.** This is the third step in the fusion of hydrogen into helium in the Sun. Note that the two helium-3 nuclei from the second step (see **Figure 16.7**) must combine before the third step becomes possible. The two protons that come out of this step have the energy to collide with other protons in the Sun and start step one again.

The ***Proton–proton chain*** summary

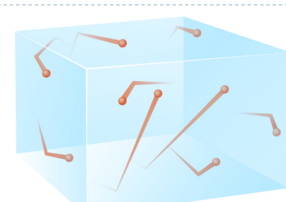


IN
4 protons

OUT
^{4}He nucleus
2 gamma rays
2 positrons
2 neutrinos

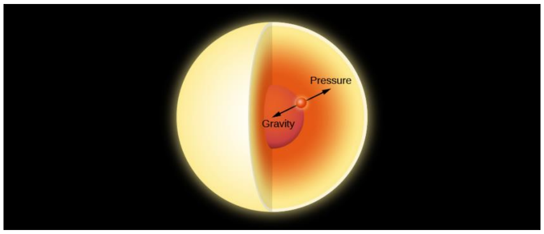
Total mass is 0.7% lower.

16.3 THE SOLAR INTERIOR: THEORY



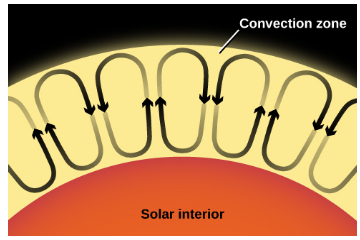
- **Gas Pressure.** The particles in a gas are in rapid motion and produce pressure through collisions with the surrounding material. Here, particles are shown bombarding the sides of an imaginary container.

Figure 16.11



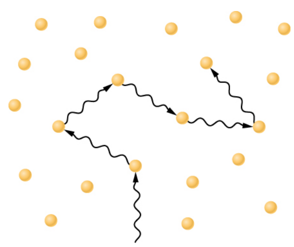
- **Hydrostatic Equilibrium.** In the interior of a star, the inward force of gravity is exactly balanced at each point by the outward force of gas pressure.

Figure 16.12

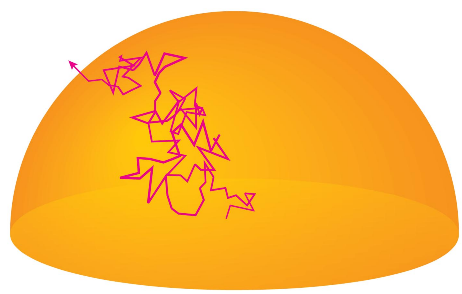


- **Convection.** Rising convection currents carry heat from the Sun's interior to its surface, whereas cooler material sinks downward. Of course, nothing in a real star is as simple as diagrams in textbooks suggest.

Figure 16.13

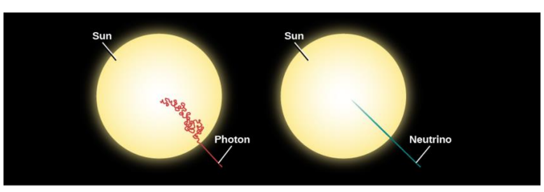


- **Photons Deep in the Sun.** A photon moving through the dense gases in the solar interior travels only a short distance before it interacts with one of the surrounding atoms. The photon usually has a lower energy after each interaction and may then travel in any random direction.



The random drunk man's path

Figure 16.14

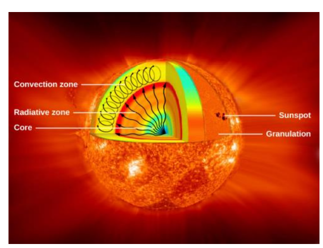


- **Photon and Neutrino Paths in the Sun.**

(a) Because photons generated by fusion reactions in the solar interior travel only a short distance before being absorbed or scattered by atoms and sent off in random directions, estimates are that it takes between 100,000 and 1,000,000 years for energy to make its way from the center of the Sun to its surface.

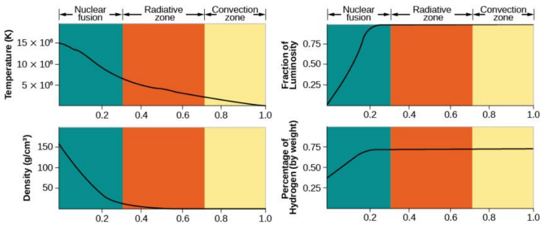
(b) In contrast, neutrinos do not interact with matter but traverse straight through the Sun at the speed of light, reaching the surface in only a little more than 2 seconds.

Figure 16.15



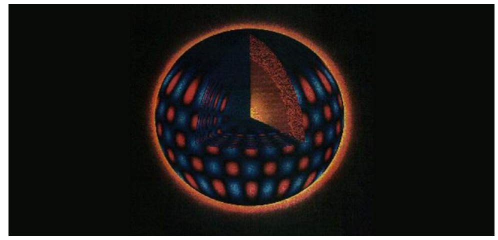
- **Interior Structure of the Sun.** Energy is generated in the core by the fusion of hydrogen to form helium. This energy is transmitted outward by radiation—that is, by the absorption and reemission of photons. In the outermost layers, energy is transported mainly by convection. (credit: modification of work by NASA/Goddard)

Figure 16.16



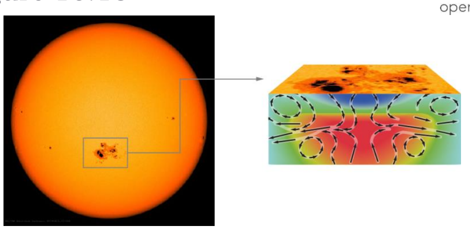
- **Interior of the Sun.** Diagrams showing how temperature, density, rate of energy generation, and the percentage (by mass) abundance of hydrogen vary inside the Sun. The horizontal scale shows the fraction of the Sun's radius: the left edge is the very center, and the right edge is the visible surface of the Sun, which is called the photosphere.

16.4 THE SOLAR INTERIOR: OBSERVATIONS



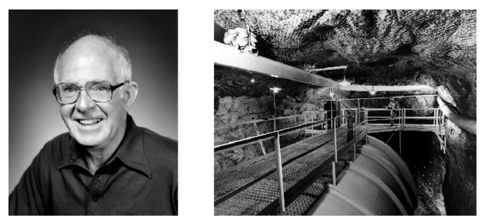
- **Oscillations in the Sun.** New observational techniques permit astronomers to measure small differences in velocity at the Sun's surface to infer what the deep solar interior is like. In this computer simulation, red shows surface regions that are moving away from the observer (inward motion); blue marks regions moving toward the observer (outward motion). Note that the velocity changes penetrate deep into the Sun's interior.

Figure 16.18



- **Sunspot Structure.** This drawing shows our new understanding, from helioseismology, of what lies beneath a sunspot. The black arrows show the direction of the flow of material. The intense magnetic field associated with the sunspot stops the upward flow of hot material and creates a kind of plug that blocks the hot gas. As the material above the plug cools (shown in blue), it becomes denser and plunges inward, drawing more gas and more magnetic field behind it into the spot. The concentrated magnetic field causes more cooling, thereby setting up a self-perpetuating cycle that allows a spot to survive for several weeks. Since the plug keeps hot material from flowing up into the sunspot, the region below the plug, represented by red in this picture, becomes hotter. This material flows sideways and then upward, eventually reaching the solar surface in the area surrounding the sunspot.

Figure 16.19



(a) (b)

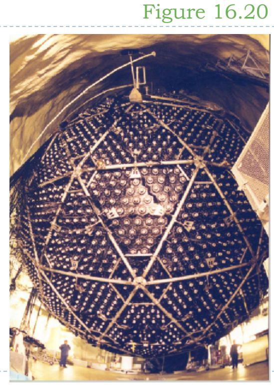
- **Davis Experiment.**

(a) The Raymond Davis received the Nobel Prize in physics in 2002.

(b) Davis' experiment at the bottom of an abandoned gold mine first revealed problems with our understanding of neutrinos. (credit a: modification of work by Brookhaven National Laboratory; credit b: modification of work by the United States Department of Energy)

Figure 16.20

- **Sudbury Neutrino Detector.** The 12-meter sphere of the Sudbury Neutrino Detector lies more than 2 kilometers underground and holds 1000 metric tons of heavy water.



Links

Reading

- 16.1optional
- 16.2
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- 16.4 optional