Astro 301/ Fall 2006
(50405)

Introduction to Astronomy
http://www.as.utexas.edu/~sj/a301-fa06

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Lecture 11: Tu Oct 10
North Korean nuclear test on Mon Oct 9 2006

North Korea claims to have conducted nuclear test on an atomic fission bomb on Oct 9, 2006.

See today’s lecture on energy released by nuclear fission.
Recent and Upcoming topics in class

Energy
-- Energy and Luminosity
-- Forms of Energy.
-- Principle of Conservation of Energy
-- Equivalence of Mass and Energy or $E=mc^2$
-- What fraction $f$ of the stored energy do different processes
  Chemical reactions
  Nuclear fusion
  Nuclear Fission
  Accretion of matter onto a black hole

-- Atomic Nuclear Fission Bomb dropped on Hiroshima and Nagasaki
  North Korean nuclear test on October 9, 2006

-- How much energy is released during nuclear fusion? The missing mass problem
# Energy and Work

## Table 4.1 Energy Comparisons

<table>
<thead>
<tr>
<th>Item</th>
<th>Energy (joules)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average daytime solar energy striking Earth, per m² per second</td>
<td>$1.3 \times 10^3$</td>
</tr>
<tr>
<td>Energy released by metabolism of one average candy bar</td>
<td>$1 \times 10^6$</td>
</tr>
<tr>
<td>Energy needed for 1 hour of walking (adult)</td>
<td>$1 \times 10^6$</td>
</tr>
<tr>
<td>Kinetic energy of average car traveling at 60 mi/hr</td>
<td>$1 \times 10^6$</td>
</tr>
<tr>
<td>Daily energy needs of average adult</td>
<td>$1 \times 10^7$</td>
</tr>
<tr>
<td>Energy released by burning 1 liter of oil</td>
<td>$1.2 \times 10^7$</td>
</tr>
<tr>
<td>Energy released by fission of 1 kg of uranium-235</td>
<td>$5.6 \times 10^{13}$</td>
</tr>
<tr>
<td>Energy released by fusion of hydrogen in 1 liter of water</td>
<td>$7 \times 10^{13}$</td>
</tr>
<tr>
<td>Energy released by 1-megaton H-bomb</td>
<td>$5 \times 10^{15}$</td>
</tr>
<tr>
<td>Energy released by major earthquake (magnitude 8.0)</td>
<td>$2.5 \times 10^{16}$</td>
</tr>
<tr>
<td>Annual U.S. energy consumption</td>
<td>$10^{20}$</td>
</tr>
<tr>
<td>Annual energy generation of Sun</td>
<td>$10^{34}$</td>
</tr>
<tr>
<td>Energy released by supernova (explosion of a star)</td>
<td>$10^{44} - 10^{46}$</td>
</tr>
</tbody>
</table>
See in-class notes

Radiative energy (light)
Sound energy
Kinetic energy
Thermal Energy
**Temperature affect the motion of atoms**

A macroscopic body (e.g., a hot kettle, a star, your hand) contains atoms that are moving randomly.

The temperature of a body determines the random speed at which its atoms move:

- **High temperature**: high speed, large thermal energy
- **Low temperature**: low speed, low thermal energy
Thermal Energy

Thermal Energy of each particle depends on temperature $T$

Total thermal energy of 2 blocks of matter having same volume is larger for block having more particles (higher density).
**The Kelvin, Celsius and Fahrenheit temperature scales**

<table>
<thead>
<tr>
<th>°K</th>
<th>Example</th>
<th>Speed of Atoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Absolute zero</td>
<td>Atoms at rest</td>
</tr>
<tr>
<td>273</td>
<td>Water freezes</td>
<td></td>
</tr>
<tr>
<td>373</td>
<td>Water boils</td>
<td>500 meters/sec</td>
</tr>
<tr>
<td>1800</td>
<td>Iron melts</td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>Iron vaporizes</td>
<td></td>
</tr>
<tr>
<td>5800</td>
<td>Sun’s surface</td>
<td>7 km/sec</td>
</tr>
</tbody>
</table>

Celsius temperature = Kelvin temperature - 273°
Celsius temperature = (Fahrenheit temperature - 32) / 1.8
Einstein’s equivalence principle

Energy stored in Mass M is given by \( E = M c^2 \)

1) Chemical reactions extract energy

\[ E = f \; M c^2 \quad \text{where} \quad f = 10^{-9} \]

2) Nuclear fission of Uranium or Plutonium extract energy

\[ E = f \; M c^2 \quad \text{where} \quad f < 10^{-3} \]

Uranium bomb on Hiroshima, Plutonium bomb on Nagasaki

3) Nuclear fusion of a mass M of H into He extract energy

\[ E = f \; M c^2 \quad \text{where} \quad f = 0.007 \]

Hydrogen bomb in 1952

4) Infall of mass M on the accretion disk of a black hole releases

\[ E = f \; M c^2 \quad \text{where} \quad f = 0.1 \]
Atomic nuclear fission bomb dropped on Hiroshima

Energy released equivalent to detonating 15,000 tons (33 million pounds) of TNT.
Atomic Nuclear Fission Bomb dropped on Nagasaki

The atomic bomb mushroom cloud seen from an American aircraft

The atomic bomb mushroom cloud over Nagasaki on August 9, 1945
Atomic Fission Bomb: Nagasaki

Nagasaki 2 days before the atomic bombing

Nagasaki 3 days after the atomic bombing
Atomic Fission Bomb: Nagasaki

DAMAGE CAUSED BY THE ATOMIC BOMB EXPLOSION

* Levelled Area..................6.7 million square meters

* Damaged Houses:
  Completely Burned ------11,574
  Completely Destroyed-----1,326
  Badly Damaged------------5,509
  Total-------------------18,409

* Casualties
  Killed------73,884
  Injured-----74,909
  Total------148,793

(Large numbers of people died in the following years from the effects of radioactive poisoning.)
North Korean nuclear test on Mon Oct 9 2006

North Korea claims to have conducted nuclear test on an atomic fission bomb on Oct 9, 2006.

Energy released is thought to be equivalent to detonating 550 tons of TNT.
How much energy is released during nuclear fusion? (The missing mass problem)

1. Energy released during nuclear fusion is related to the missing mass or mass difference between starting and end products: See in class notes
   Fusion energy \( E = (\text{initial mass} - \text{end mass}) c^2 \)

2. Where does this relationship come from? It can be derived very simply from the principle of conservation of energy: See in class notes

3. We stated earlier that the nuclear fusion of a mass \( M \) of \( H \) into He extracts energy \( E = f \, M c^2 \) where \( f = 0.007 \)
   Where does the number 0.007 come from? We can derive it from the first principles in (1) above: See in class notes
The Sun is powered by nuclear fusion of H into He in its core

- Nuclear fusion occurs in core where temp and pressure are very high.
  T drops from 1.5 x 10^7 K in the core down to 5800 K at the surface or photosphere
- The energy released is transported from core to the photosphere where it is released as light and heat.