Test 1 results

Section 1

**Column Statistics for: test1**

- Count: 85
- Average: 33.0
- Median: 35.0
- Maximum: 47.0
- Minimum: 14.0
- Standard Deviation: 7.85

**Grade Histogram**

Score Range | Frequency
---|---
[0.00, 4.70) | 3
[4.70, 9.40) | 1
[9.40, 14.10) | 7
[14.10, 18.80) | 14
[18.80, 23.50) | 16
[23.50, 28.20) | 15
[28.20, 32.90) | 9
[32.90, 37.60) | 1
[37.60, 42.30) | 1
[42.30, 47.00) | 1
[47.00) | 1
Test 1 result

Section 2

Column Statistics for: test1

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>136</td>
</tr>
<tr>
<td>Average</td>
<td>32.1</td>
</tr>
<tr>
<td>Median</td>
<td>32.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>46.0</td>
</tr>
<tr>
<td>Minimum</td>
<td>7.0</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>8.13</td>
</tr>
</tbody>
</table>

Grade Histogram

- Score Range
  - (0.00, 4.60)
  - [4.60, 9.20)
  - [9.20, 13.80)
  - [13.80, 18.40)
  - [18.40, 23.00)
  - [23.00, 27.60)
  - [27.60, 32.20)
  - [32.20, 36.80)
  - [36.80, 41.40)
  - [41.40, 46.00)
  - [46.00, 46.00]

Frequency
SOHO
10 years of operations
1995-2005

http://sohowww.nascom.nasa.gov/
## Properties of the Sun

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius</td>
<td>$\sim 7 \times 10^5$ km ($\sim 110 , R_{\text{Earth}}$)</td>
</tr>
<tr>
<td>Mass</td>
<td>$2 \times 10^{30}$ kg ($\sim 3 \times 10^5 , M_{\text{Earth}}$)</td>
</tr>
<tr>
<td>Luminosity</td>
<td>$3.8 \times 10^{26}$ W</td>
</tr>
<tr>
<td>Composition</td>
<td>70% hydrogen, 28% helium, 2% heavier elements</td>
</tr>
<tr>
<td>Temperature</td>
<td>$\sim 6000$ K (average surface)</td>
</tr>
<tr>
<td></td>
<td>4,500 K (sunspots), $1.5 \times 10^7$ K (core)</td>
</tr>
<tr>
<td>Rotation Rate</td>
<td>25 days (equator)</td>
</tr>
<tr>
<td></td>
<td>30 days (pole)</td>
</tr>
<tr>
<td>Age</td>
<td>$\sim 4.6$ billion yrs</td>
</tr>
</tbody>
</table>

A ball of plasma!
The Sun is the Largest Object in the Solar System

- The Sun contains more than 99.85% of the total mass of the solar system
- If you put all the planets into the Sun, they would not fill up its volume
- ~110 Earths or 10 Jupiters fit across the diameter of the Sun
Structure of the Sun

From outside to inside:

- solar wind
- corona $\sim 10^6$ K
- chromosphere $\sim 10^4$ K
- photosphere $\sim 6000$ K
- convection zone
- radiation zone $\sim 10^7$ K
- core $\sim 1.5 \times 10^7$ K
  density 100 g/cm$^3$
How does the Sun shine?

In the ~1800’s,

- chemical reaction? → No, it doesn’t release enough energy
  
  (reaction requires oxygen)

- gravitational contraction? → No, the age doesn’t match
  
  (can’t support solar luminosity long enough)

- the answer was found in ~1930: nuclear fusion!
Nuclear Fusion

\[ 4 \, ^1\text{H} \rightarrow \, ^{4}\text{He} + \text{energy} \]

mass of 4 protons: \( 6.6943 \times 10^{-27} \text{ kg} \)

mass of helium nucleus: \( 6.6466 \times 10^{-27} \text{ kg} \)

difference in mass: \( 0.0477 \times 10^{-27} \text{ kg} \)

\(^{1}\text{H}= \text{one proton,} \quad ^{4}\text{He}=\text{2 protons + 2 neutrons}\)
This mass difference is the energy source of the Sun!

$$E=mc^2$$  
(Einstein 1905)  
Special Theory of Relativity

energy = mass x (speed of light)$^2$

$$E = 0.0477 \times 10^{-27} \text{ kg} \times (3 \times 10^8 \text{ m/s})^2$$

$$= 4.3 \times 10^{-12} \text{ Joules}$$

Tiny amount of energy, but MANY of these reactions take place in the core of the Sun!
Quiz

How was the chemical composition of the Sun 3 billion years ago different than what it is today?

A. It had more hydrogen then.
B. It had more helium then.
C. It had more nitrogen then.
D. It had more oxygen then.
Lecture-Tutorial (LT):
Sun Size

• Work with a partner!
• Read the instructions and questions carefully.
• Discuss the concepts and your answers with one another.
• Come to a consensus answer you both agree on.
• If you get stuck or are not sure of your answer, ask another group.
• If you get really stuck or don’t understand what the LT is asking, ask for help.
Convective Zone

Bright spots appear on Sun's surface where hot gas is rising . . .

. . . then the gas sinks after it has cooled off.
Granules in the Photosphere

Caused by rising & sinking in the convective zone

hot -- rise -- light
cold -- sink -- dark

Movie:
http://solarb.msfc.nasa.gov/movies/gb_20061102bw.mpg
Sunspots are caused by bundled magnetic fields

- Sunspots are cooler (4500 K)
- that’s why they ‘look’ black (just a contrast)
- magnetic fields constrain the flow of gas
Sunspots

- They come in pairs.
- They move with the rotation of the Sun.
Sunspots
See this and other SOHO movies at http://sohwww.nascom.nasa.gov/
Solar cycles

- 7-15 yr cycle; average 11 year cycle
- # of sunspots correlate with solar cycle
Solar Flares

- show the magnetic field lines (loops)
- charged particles are constrained to those magnetic fields, and emit X-rays
- this is an X-ray image from SOHO
Magnetic activity also causes solar prominences that erupt high above the Sun’s surface.
Solar Wind & Earth’s Magnetosphere
Relevance of Earth’s protective magnetosphere

- Protects against Solar Flares - violent explosions on the Sun releasing large burst of charged particles into the solar system
- Protects against Solar Wind - dangerous stream of charged particles constantly coming from the Sun
- Creates Northern Lights (Aurora Borealis) - solar wind particles interact with Earth’s magnetic field
The Sun’s luminosity comes primarily from

(A) chemical burning
(B) the mechanical energy of turbulence
(C) nuclear fusion
(D) gravitational contraction
(E) all of the above are comparable in importance

(for E, show a white side)
Which statement do you think best represents the size comparison between the diameter of the Sun and the distance between the Moon and Earth? The Sun’s diameter is

A. smaller than the distance between the Moon and Earth.
B. approximately equal to the distance between the Moon and Earth.
C. larger than the distance between the Moon and Earth.
The dark spots located on this solar image are sunspots. How does the size of Earth compare to the size of the sunspot that is identified on the right side of the image of Sun?

A. Earth and the sunspot are about the same size.
B. The sunspot is much larger than Earth.
C. The sunspot is much smaller than Earth.