**Supernovae—March 23**

- Where were the elements in the baby made?
  - Carbon was made and expelled by giants
  - Iron was made in massive stars and expelled by supernovae
- Supernova
  - Neutron star
  - Black hole
- Study guide for test 3

**Guest star of 1054**

- Records of Sung Dynasty
  - In the first year of the period Chih-ho, ... a guest star appeared several degrees SE of Thien-kuan. After more than a year it gradually became invisible—p564.
- Gas expelled in 1054AD, still glowing
- Other SN
  - 1572 Tycho
  - 1604 Kepler

**Supernova 1987A**

- Exploded in Large Magellanic Cloud
  - LMC is small galaxy that orbits our own Milky Way Galaxy.

**Supernova remnants**

- We expect one supernova in Milky Way every 25-100 yrs.

- Crab: 1,000 yrs old
- Cygnus Loop: 20,000 yrs old, 2500 LY away.
- IC 443: 8000 yrs old
Supernovae

• Explosion releases enormous energy
• Luminosity in photons temporarily exceeds that of whole galaxy full (100 billion) of stars.

What is a supernova? Why sun becomes a white dwarf, not a supernova

• In future double-shell burning sun, hot enough to burn $^3\text{He} \rightarrow ^{\text{3}}\text{C}$
• When He exhausted, gravity wins, and core contracts.
• Temperature rises.
• Electrons are so tight that they become degenerate.
• New source of pressure to resist gravity.
• Temperature not hot enough to burn carbon.

What is a supernova? Why massive star becomes a supernova

• In future double-shell burning massive star, hot enough to burn $^3\text{He} \rightarrow ^{\text{3}}\text{C}$
• When He exhausted, gravity wins, and core contracts.
• Temperature rises by larger amount b/c gravity is stronger.
• Temperature hot enough to burn carbon.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Min. Temp.</th>
</tr>
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<tbody>
<tr>
<td>$^4\text{He} \rightarrow ^{\text{4}}\text{He}$</td>
<td>$10^9$ K</td>
</tr>
<tr>
<td>$^3\text{He} \rightarrow ^{\text{3}}\text{C}$</td>
<td>$2 \times 10^9$</td>
</tr>
<tr>
<td>$^{13}\text{C} + ^{\text{4}}\text{He} \rightarrow ^{\text{16}}\text{O}, ^{\text{10}}\text{Ne}, ^{\text{11}}\text{Na}, ^{\text{12}}\text{Mg}$</td>
<td>$8 \times 10^9$</td>
</tr>
<tr>
<td>$^{16}\text{O} \rightarrow ^{\text{16}}\text{O}, ^{\text{12}}\text{C}$</td>
<td>$1.5 \times 10^9$</td>
</tr>
<tr>
<td>$^{20}\text{Ne} + ^{\text{4}}\text{He} \rightarrow ^{24}\text{Mg}$</td>
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<td>$^{24}\text{Mg}$</td>
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What is a supernova? Why massive star becomes a supernova

• Hot enough to burn $^4\text{He} + ^{12}\text{C} \rightarrow ^{16}\text{O}$, etc
• When C exhausted, gravity wins, and core contracts.
• Temperature rises.
• Temperature hot enough to burn neon.
• $^{20}\text{Ne} + ^{4}\text{He} \rightarrow ^{24}\text{Mg}$
• Disaster with iron
  • Burning releases energy
  • Fusing iron takes up energy
• Gravity finally wins.
What is a supernova? Why massive star becomes a supernova

- Disaster with iron
  - Burning releases energy
  - Fusing iron takes up energy
- Gravity finally wins.
- Star collapses in few seconds
- Rebounds as supernova
  - Reason for rebounding is topic of current research
- Expel outer layers

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<td>$4 , \text{H} \rightarrow , \text{He}$</td>
<td>$10^9 , \text{K}$</td>
</tr>
<tr>
<td>$3 , \text{He} \rightarrow , \text{C}$</td>
<td>$2 \times 10^9$</td>
</tr>
<tr>
<td>$\text{C} + , \text{He} \rightarrow , \text{O, Ne, Na, Mg}$</td>
<td>$8 \times 10^9$</td>
</tr>
<tr>
<td>$\text{Ne} \rightarrow , \text{O, Mg}$</td>
<td>$1.5 \times 10^9$</td>
</tr>
<tr>
<td>$\text{O} \rightarrow , \text{Mg, S}$</td>
<td>$2 \times 10^9$</td>
</tr>
<tr>
<td>$\text{Si} \rightarrow , \text{Fe peak}$</td>
<td>$3 \times 10^9$</td>
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</table>

1. What prevents the sun from becoming a supernova?
   a. Iron core is stable.
   b. Degeneracy pressure prevents temperature from rising.
   c. Carbon burning.
   d. That is wrong; the sun will become a supernova.
2. If neon was the most stable element, massive stars live
   a. longer
   b. shorter

What is left?

- Outer layers expelled into space. New stars may form.
- Core becomes
  - Neutron star. One in Crab. Pulses every $1/30 \, \text{s}$.
  - Black hole
- Neutron star
  - Normally
    - neutron$\rightarrow$proton+electron+neutrino+energy
  - Pressure is so high that
    - proton+electron+energy$\rightarrow$neutron+neutrino
  - Whole star is like a big nucleus of neutrons.
  - Neutrons are degenerate
  - Star is size of Lansing

1. Missouri Club
   - Friday, 9:00am
   - Room 1410?
2. Study guide
   - Will put on web by end of day.
   - Big ideas
   - Medium-sized ideas
   - Questions