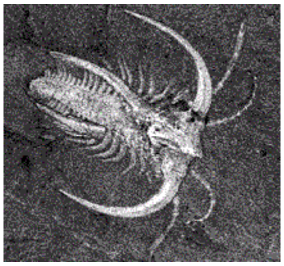
Formation of Helium in the BB

- A fossil is a remnant or trace of the past. Amount of helium is a fossil from the Big Bang.
  - Mass He/Mass H=1:3
  - neutrons/protons=1:7
- Three snapshots
  - 0.001s. n/p=1:1
  - 3min. n/p=1:7
  - Now. n/p=1:7



Fossil from Burgess Shale

- Please rate your class at
  - rateyourclass.msu.edu
  - Closes on May 8th.
- Open house at MSU Telescope
  - See the Orion Nebula, the moon, & other wonders through the 24" telescope
  - Friday and Saturday, May 1 and 2, from 9:30pm - 11pm, weather permitting
  - Observatory is on Farm Lane & Forest Rd (south of campus)
- Homework 7
  - Due 6:00 pm on Tues, April 28th, just before Missouri Club
- Missouri (Show Me) Club
  - Room 1415, today, 7:00-8:00pm
- Final Exam
  - Wed, May 6th, 3:00-5:00
  - Room 1410 (our classroom)
  - One 8½ ×11 cheat sheet.
  - Covers entire course with more emphasis on galaxies & cosmology.

1. At the present time, n:p=1:7. Where are all of those neutrons?
   A. in ^{4}He (helium with 2p & 2n)
   B. in ^{16}O (oxygen with 8p & 8n)
   C. in ^{12}C (carbon with 6p & 6n)

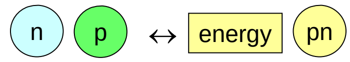
Neutrons/protons when U was 0.001s old

p 2 MeV ↔ n

- 0.001s
  - Temperature = 400 BK
  - E=40 MeV is much greater than cost to be a neutron
  - n:p = 1:1

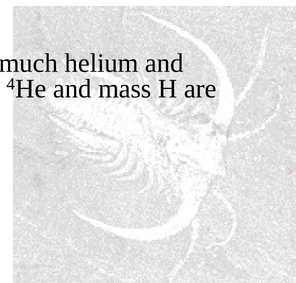
1. Later (at 0.01s) the temperature of the U is ___.
   A. warmer
   B. cooler
   C. same
2. At later times (0.01s), n/p is ___.
   A. higher
   B. lower
   C. same

Production of deuterium



- Production of deuterium (hydrogen with one neutron)
  - n + p ↔ ^{2}H + energy
  - If the universe is too hot, radiation has so much energy that deuterium is broken apart.
- Once deuterium forms and becomes stable, helium forms quickly, and all of the neutrons are locked in ^{4}He.
- 0.001s
  - Temperature = 400 BK
  - E=40 MeV is much greater than cost to be a neutron
  - n:p = 1:1
  - Deuterium is easily broken apart.

1. If deuterium & ^{4}He could form at 0.001s, how much helium and hydrogen would form from 16 nucleons? Mass ^{4}He and mass H are
   - A. 0 and 16
   - B. 8 and 8
   - C. 16 and 0
   - D. 4 and 12



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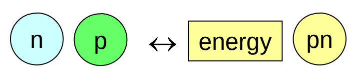

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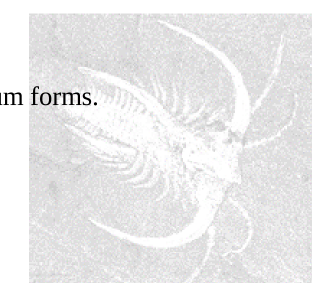
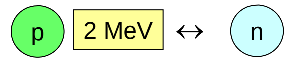
2. If deuterium & ^{4}He form later, does ___ helium forms.
   - A. less
   - B. more
   - C. same amount of



Neutrons/protons when U was 3min old

- As universe cools, n/p drops because the cost of being a neutron is more and more expensive.
- 3 min
  - Temperature = 1 BK
  - E=0.1MeV is much less than cost to be a neutron
  - n:p = 1:7



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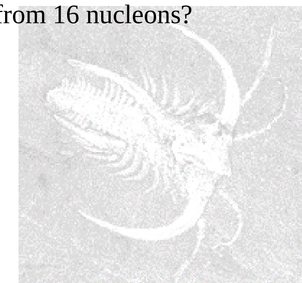

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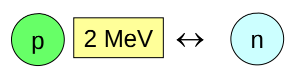

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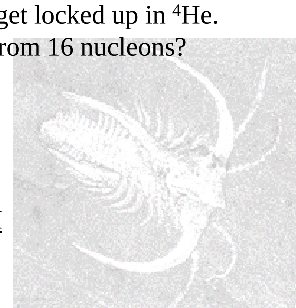
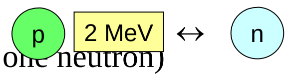
- <u>25% of mass is in ^{4}He and 75% of mass is in H</u>



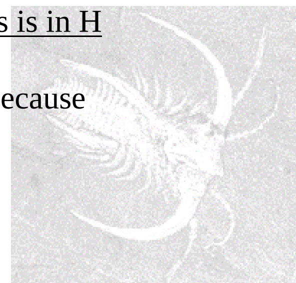
Neutrons/protons at the present time

- Now, 13Byr
  - Temperature = 2.7K
  - E=tiny
  - n:p = 1:7
- Production of deuterium (hydrogen with one neutron)
  - n + p ↔ ^{2}H + energy



- At 3min, deuterium becomes stable. Neutrons get locked up in ^{4}He.
- <u>25% of mass is in ^{4}He and 75% of mass is in H</u>
- Neutrons are safely in helium.

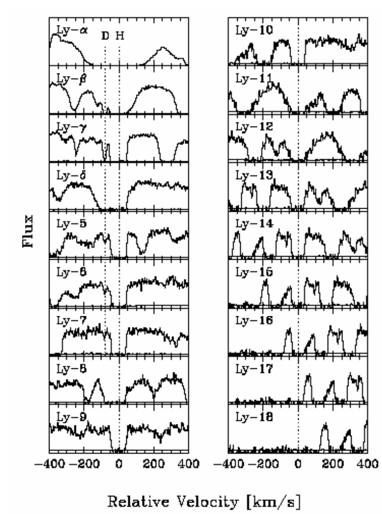
1. Amount of ^{4}He has increased slightly because
   - A. helium is made in stars
   - B. neutrons are still changing into protons.



“Collecting the Fossil”

- ^{4}He, ^{7}Li, ^{2}H, & ^{3}He are made in BB.
  - Lots of ^{4}He
  - Trace amounts of ^{7}Li, ^{2}H, & ^{3}He. Diagnostics.
- Measure abundances with spectra of “primordial objects”
  - First stars in our galaxy, made before much of the material had been processed through stars.
  - Dwarf galaxies, where material is processed through stars very slowly.
- Deuterium ^{2}H has same spectra as hydrogen ^{1}H but slightly shifted.
  - Abundance of ^{2}H: Strength of ^{2}H spectral line compared with ^{1}H line.

400km/s=d wavelegnth = wl/750



O'Meara, et al., 2001, ApJ 552, 718.