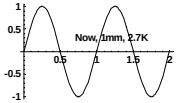
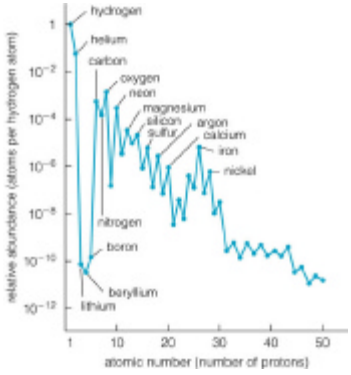
When the Universe was 3 Minutes Old—13 Apr

- What did the Cosmic Background Radiation, now a cool 2.7 K, do in the past?
- The universe when it was 3 minutes old
- Why is there so much helium in the sun?
  - Helium formed when universe was 3 minutes old





The Younger Universe

- Fill a 2-L bottle with an average of the present universe
- Matter
  - Mass=2×10^{-29}kg
    - same as 1/100 hydrogen atom
- Light has mass b/c light has energy
  - $E=m c^2$. $E=eV/4{,}000$
  - $E \propto T \propto 1/\lambda$ (Wien)
- Light
  - 0.8 M photons
  - Mass of each photon= 4×10^{-40}kg
  - Mass of light=3×10^{-34}kg
    - Same as 1/5,000,000 hydrogen atom
- When universe was half the present size,
  - 2×2×2 present-day bottles fit in a single bottle

1. How much mass was in a 2L bottle back then? Mass is same as
   a. 1/100th hydrogen atom
   b. 1/50th hydrogen atom
   c. 1/25th hydrogen atom
   d. 1/12th hydrogen atom
   e. 1/6th hydrogen atom

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2. How many photons were in a 2L bottle back then?
   a. 0.8 Million
   b. 1.6 Million
   c. 3 Million
   d. 6 Million
   e. 12 Million

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3. The mass of the light in a 2L bottle back then was
   a. 1/5,000,000th m_H
   b. 1/2,500,000th m_H
   c. 1/1,300,000th m_H
   d. 1/600,000th m_H
   e. 1/300,000th m_H

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  - $E \propto T \propto 1/\lambda$ (Wien)
- Light
  - 0.8 M photons
  - Mass of each photon= 4×10^{-40}kg
  - Mass of light=3×10^{-34}kg
    - Same as 1/5,000,000 hydrogen atom

- When universe was half the present size,
  - $2\times2\times2$ present-day bottles fit in a single bottle
- The mass of matter is bigger by factor of $2^3=8$
- The mass of the light is bigger by a factor of $2^4=16$

Then Now

The Younger Universe

- Fill a 2-L bottle with an average of the present universe
- Matter
  - Mass=2×10^{-29}kg
    - same as 1/100 hydrogen atom
- Light has mass b/c light has energy
  - $E=m c^2$. $E=eV/4{,}000$
  - $E \propto T \propto 1/\lambda$ (Wien)
- Light
  - 0.8 M photons
  - Mass of each photon= 4×10^{-40}kg
  - Mass of light=3×10^{-34}kg
    - Same as 1/5,000,000 hydrogen atom

- When universe was hot enough to roast a chicken
  - Distances were 200 times smaller
  - $200\times200\times200$ present-day bottles fit in a single bottle
- The mass of matter is bigger by factor of 200^3
- The mass of the light is bigger by a factor of 200^4

4. Would you notice the difference between an empty and filled bottle of matter? Of light?
   a. YY
   b. YN
   c. NY
   d. NN

Now

The Younger Universe

- Fill a 2-L bottle with an average of the present universe
- Matter
  - Mass=2×10^{-29}kg
    - same as 1/100 hydrogen atom
- Light has mass b/c light has energy
  - $E=m c^2$. $E=eV/4{,}000$
  - $E \propto T \propto 1/\lambda$ (Wien)
- Light
  - 0.8 M photons
  - Mass of each photon= 4×10^{-40}kg
  - Mass of light=3×10^{-34}kg
    - Same as 1/5,000,000 hydrogen atom

- When universe was 3minutes old
  - Distances were 400M times smaller
  - Mass of matter in bottle 1mg
  - Mass of light in bottle 9kg

5. Would you notice the difference between an empty and filled bottle of matter? Of light?
   a. YY
   b. YN
   c. NY
   d. NN

Reactions important for cosmology

- Rough numbers
  - Chemical reactions: 1eV.
  - Nuclear reactions: 1MeV
- Hydrogen ionizes
  - H + energy $\rightarrow$ p + e^-
  - E=0.23eV in space
- Deuterium forms
  - p + n $\rightarrow$ deuterium + energy
  - E=0.1MeV
- Proton changes into neutron
  - p + energy $\rightarrow$ n + e^+ + ν
  - E=2MeV

- Now
  - 2.7K
  - E=eV/4000
- Roast chicken epoch
  - 500 K
  - E=eV/20
- 3 min
  - 1 BK
  - E=0.1MeV
- 0.001s
  - 400 BK
  - E=40 MeV