Name: ______________________________

Partner(s): ___________________________

LAB #13 PARTICLE SOUP: BIG BANG NUCLEOSYNTHESIS

Purpose

The student explores how helium was made in the Big Bang.

Introduction

Very little helium is made in stars. Yet the universe is roughly 1/4 helium and 3/4 hydrogen by mass. How can this be? Early in the Big Bang the Universe was hot and dense (like the core of a star) and protons could fuse together to make some helium. The fact that the Universe is 1/4 helium is very good evidence for the existence of the Big Bang and a hot early Universe.

Scenario 1

In the very early Universe, (before 0.01 seconds), the temperature was too high for even protons and neutrons to exist. Certainly, nuclei of atoms, which require protons and neutrons, could not exist. If nuclei did form, high energy radiation (gamma rays), tore them apart. Once the Universe expanded and cooled to 100 billion degrees, neutrons and protons could persist. Not only that, but they could switch back and forth:

$$\text{neutron} \ + \ \text{neutrino} \rightarrow \text{proton} \ + \ \text{electron} \tag{1}$$

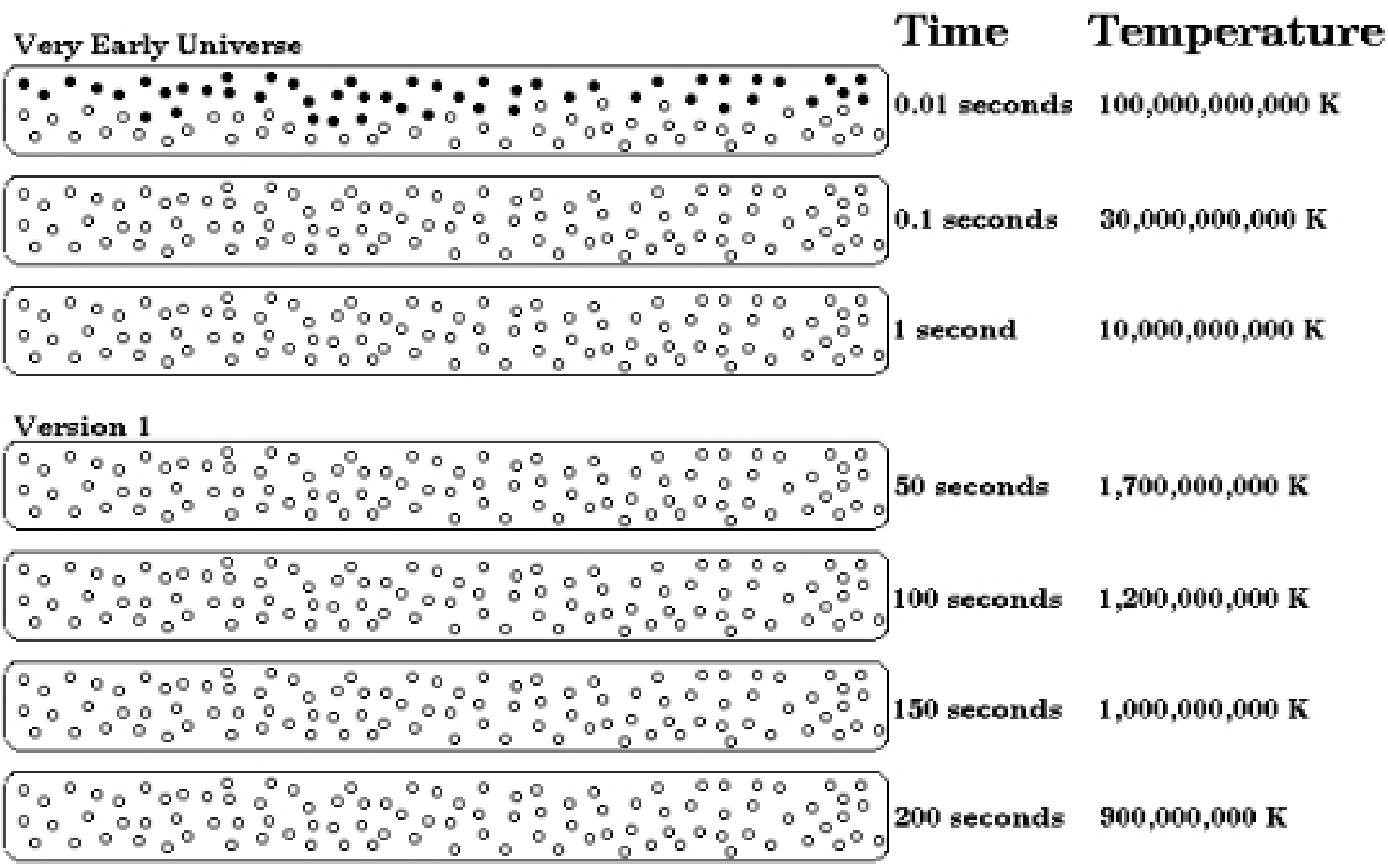
$$\text{neutron} \ + \ \text{positron} \rightarrow \text{proton} \ + \ \text{anti} - \text{neutrino} \tag{2}$$

$$\text{neutron} \rightarrow \text{proton} \ + \ \text{neutrino} \ + \ \text{electron} \tag{3}$$

The total number of particles stays the same but the fraction which are neutrons depends on the temperature, (and nothing else). Another way to say this is that the neutrons and protons numbers are in thermal equilibrium. To stay in thermal equilibrium all of the reactions above need to be occurring frequently.

Neutrons require more energy to make because they are heavier than protons ($E = mc^2$). As the temperature drops, there is less energy available, and the reactions begin to favor protons (see Table 1).

Temperature	Equilibrium Neutron Fraction	Equilibrium Reaction Speed)
100,000,000,000 K	50/100	Fast
30,000,000,000 K	37/100	Slow
10,000,000,000 K	18/100	Stopped
3,000,000,000 K	1/100	Stopped
1,700,000,000 K	0.01/100	Stopped
1,200,000,000 K	0.0004/100	Stopped
1,000,000,000 K	0.00003/100	Stopped
900,000,000 K	0.000006/100	Stopped



1. **(2 pts)** Here are shown 100 particles (protons or neutrons) in a box at various times. Using the Equilibrium fractions given in Table 1, indicate how many are neutrons at 0.1 seconds and 1 second by marking the circles. 0.01 seconds is already marked.

2. **(2 pts)** Use version 1 to indicate the number of neutrons at 50 seconds, 100 seconds, 150 seconds and 200 seconds.

3. **(2 pts)** In version 1, how many neutrons are left at 50 seconds or later?

4. **(2 pts)** The Universe is too hot to make helium before 150 seconds. In version 1, how much helium was made in the Big Bang (remember that helium is made of two protons and two neutrons)?

5. **(2 pts)** Look at the equilibrium reaction speed column in Table 1. Why might the equilibrium neutron fraction be incorrect at 50 seconds?

Scenario 2

If the Equilibrium reactions have stopped then neutrons simply decay:

$$\text{neutron} \rightarrow \text{proton} + \text{neutrino} + \text{electron} \tag{4}$$

The decay has a half life of 600 seconds. In 600 seconds, a neutron is as likely to turn into a proton as it is to stay a neutron. This can be simulated by tossing a coin. If it lands heads up, the neutron has turned into a proton. The chance of decaying in 50 seconds is much less, one in 16. The neutron will turn into a proton if four coins land heads up.