Directions: *Fill in the blanks with the respective epochs for each section. Many of these topics will NOT be tested on, but are very interesting because it’s the history of our Universe. I will designate some relevant sections to the test via asterisks (\*). NOTE: Don’t memorize the times. Memorize what happens and what things mean.*

 1. Big Bang (BB) occurs: The universe expands very rapidly from a dense gravitational singularity.

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| 1. Electroweak Epoch\*
 | 1. Planck Epoch\*
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| 1. Grand Unification Epoch\*
 | 1. Inflationary Epoch\*
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\_\_\_\_ 2. 10-43 s after BB: Temperature is high enough such that the 4 fundamental forces of nature are all unified in one fundamental force (Theory of Everything). Need quantum gravity to explain because General Relativity breaks down due to quantum effects.

\_\_\_\_ 3. 10-43 s to 10-36 s after BB: Universe cools down and the super-unified force separates into the Grand Unified Force and the Gravitational Force. This epoch ends when the Grand Unified Force separates further into the Electroweak and Strong Nuclear Force at around. This transition should also produce many magnetic monopoles which aren’t observed, but this problem is solved by inflation theory.

\_\_\_\_ 4. 10-36 s to 10-12 after BB: Temperature is now low enough to separate the Strong Nuclear Force from the Electroweak Force (also the ending of the previous epoch).

\_\_\_\_ 5. Ends 10-32 s after BB: This is an era of accelerating expansion in which the Universe becomes very homogenous on large scales.

Early Universe (post-inflation)

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| --- | --- |
| 1. Recombination\*
 | 1. Lepton Epoch
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| 1. Photon Epoch
 | 1. Quark Epoch
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| 1. Hadron Epoch
 | 1. Nucleosynthesis\*
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\_\_\_\_ 6. 10-12 s to 10-6 s after BB: The fundamental interactions of the four fundamental forces have taken their present forms, but the temperature of the Universe is still too high to allow quarks to bind together to form hadrons.

\_\_\_\_ 7. 10-6 s to 1s after BB: The Universe is composed of quark-gluon plasma that cools down until hadrons, including baryons such as protons and neutrons, to form. (At approximately 1s after BB, neutrinos decouple and now freely travel through space, producing a cosmic neutrino background analogous to CMB.)

\_\_\_\_ 8. 1s to 10s after BB: Majority of hadrons and anti-hadrons annihilate each other at the end of the previous epoch, leaving leptons and anti-leptons to dominate mass of Universe. At the end of this epoch, the temperature cools such that no new lepton-anti-lepton pairs are formed and they annihilate each other, leaving a small amount of leptons behind.

\_\_\_\_ 9. 10s to 380,000 yrs after BB: After the end of the previous epoch, the Universe is now dominated mostly by photons. These photons interact with charged protons and electrons for the next 380,000 yrs. In essence, the Universe is “filled with light”.

\_\_\_\_ 10. 3 min to 20 min after BB: During the photon epoch, the temperature of the Universe drops to a point where atomic nuclei can form. Protons and neutrons combine into atomic nuclei through nuclear fusion. The majority of the atoms produced are Hydrogen and Helium, with trace amounts of other atoms. Heavier elements aren’t produced because the temperature and density of the Universe drops to a point where fusion won’t occur for heavier elements.

\_\_\_\_ 11. 377,000 yrs after BB: Before this time, the Universe was very hot and ionized, meaning there are free electrons swimming around, not bound to nuclei. As the Universe cools down, the electrons are captured by hydrogen and helium ions, forming neutral atoms. Before this time, the Universe was “opaque” because the photons would get scattered after traveling a short distance. At this time (377,000 yrs after BB), the Universe became transparent allowing photons to travel without becoming scattered (as much). Therefore, in present day, we can detect these photons and they form the Cosmic Background Radiation.

Structure Formation Era (in chronological order)

12. Formation of Stars

13. Formation of Galaxies

14. Formation of Groups/Clusters/Superclusters

15. Formation of Solar System (8 billion yrs after BB)

16. Today (13.7 billion yrs after BB)