

**A Brief History of Time**  
John C. Baez, September 23, 2004

*Note: all figures are approximate!*

**Working Backwards from Now**

- 60 years ago — Invention of the computer.
- 130 years ago — Invention of the telephone.
- 180 years ago — Fossil fuel revolution: coal, trains.
- 540 years ago — Invention of the printing press.
- 5,500 years ago — Invention of the wheel, writing.
- 8,800 years ago — The first cities.
- 10,300 years ago — End of the latest ice age.
- 18,000 years ago — Cultivation of plants, herding of animals.
- 35,000 years ago — Invention of the calendar, extinction of Neanderthals.
- 600,000 years ago — First *Homo sapiens*.
- 1.4 million years ago — First firemaking by humans.
- 1.9 million years ago — First *Homo erectus*.
- 5 million years ago — Humans split off from other apes (gorillas and chimpanzees).
- 21 million years ago — Apes split off from other monkeys.
- 24 million years ago — First grasses.
- 67 million years ago — Asteroid hit Mexico, causing ‘Cretaceous-Tertiary extinction’.  
End of dinosaurs. 50% of all species died out!
- 114 million years ago — First modern mammals.
- 150 million years ago — First birds.
- 205 million years ago — Pangaea split into separate continents. Triassic-Jurassic extinction.  
End of large amphibians, many reptiles.
- 235 million years ago — First dinosaurs, flowers.
- 251 million years ago — Permian-Triassic extinction. 90% of all species died out!
- 313 million years ago — First reptiles.
- 370 million years ago — Devonian extinction. 70% of marine species died out!  
First amphibians, trees.
- 395 million years ago — First insects on land.
- 440 million years ago — Ordovician-Silurian extinction. Most marine species died out.
- 670 million years ago — First animals.
- 1.3 billion years ago — First plants.
- 1.6 billion years ago — First blue-green algae.
- 1.8 billion years ago — First purple bacteria; Earth’s atmosphere gets oxygen.
- 3.9 billion years ago — Asteroid impacts gradually come to a halt.
- 4 billion years ago — First life on Earth.
- 4.45 billion years ago — Formation of Earth complete; storm of asteroid impacts.
- 4.55 billion years ago — Formation of the Sun.
- 13.5 billion years ago — First stars.
- 13.7 billion years ago — The Big Bang: beginning of the universe as we know it!

## Working Backwards to the Big Bang

13.7 billion years after the Big Bang: now.  
Temperature: 2.726 Kelvin

*Kelvin = degrees Centigrade above absolute zero. The melting point of water is 273 Kelvin; the boiling point is 373 Kelvin.*

200 million years after the Big Bang: 'reionization': first stars heat and ionize hydrogen gas.  
Temperature: roughly 50 Kelvin.

380 thousand years after the Big Bang: 'recombination': hydrogen gas cools down to form molecules.  
Temperature: 3000 Kelvin.

10 thousand years after the Big Bang: end of the radiation-dominated era.  
Temperature: 12,000 Kelvin.

1000 seconds after the Big Bang: decay of lone neutrons.  
Temperature: roughly 500 million Kelvin.

180 seconds after the Big Bang: beginning of 'nucleosynthesis': formation of helium and other elements from hydrogen  
Temperature: roughly 1 billion Kelvin.

10 seconds after the Big Bang: annihilation of electron-positron pairs.  
Temperature: roughly 5 billion Kelvin.

1 second after the Big Bang: decoupling of neutrinos.  
Temperature: roughly 10 billion Kelvin

100 microseconds after the Big Bang: annihilation of pions.  
Temperature: roughly 1 trillion Kelvin

50 microseconds after the Big Bang: 'QCD phase transition': quarks get bound into neutrons and protons.  
Temperature: 1.7-2.1 trillion Kelvin

10 picoseconds after the Big Bang: 'electroweak phase transition': electromagnetic and weak force become different.  
Temperature: 1-2 quadrillion Kelvin.

*Note: a picosecond is a trillionth of a second. Before this the temperatures were so high that our knowledge of physics is unable to say for sure what happened, though experts have some good guesses.*

## Working Forwards to the Future

1.1 billion years from now: the Sun becomes 10% brighter than today. The Earth's atmosphere dries out.

3 billion years from now: the Andromeda Galaxy collides with our galaxy. Many solar systems are destroyed.

3.5 billion years from now: the Sun becomes 40% brighter than today. If the Earth is still orbiting the sun, its oceans evaporate.

5.4 billion years from now: the Sun's core runs out of hydrogen, and it enters its first red giant phase, becoming 1.6 times bigger and 2.2 times brighter than today.

6.5 billion years from now: the Sun becomes a full-fledged red giant, 170 times bigger and 2400 times brighter than today.

6.7 billion years from now: the Sun starts fusing helium and shrinks back down to 10 times bigger and 40 times brighter than today.

6.8 billion years from now: the Sun runs out of helium and, too small to start fusing carbon and oxygen, enters a second red phase. It is 180 times bigger and 3000 times brighter than today.

6.9 billion years from now: the Sun begins to pulsate every 100,000 years, ejecting more and more mass in each pulse, and finally throwing off all but the hot inner core, becoming a white dwarf.

.....

$10^{17}$  years from now: all white dwarf stars cool to black dwarfs with a temperature of at most 5 Kelvin.

$10^{19}$  years from now: all galaxies 'boil off', gradually losing their dead stars to intergalactic space.

$10^{23}$  years from now: all galactic clusters boil off. Temperature:  $10^{-13}$  Kelvin.

From then on: the Universe expands exponentially and cools down to a temperature of  $10^{-30}$  Kelvin. All black holes eventually evaporate, and all other forms of matter eventually disperse into individual elementary particles.

*Note: this story leaves out all the exciting twists due to future discoveries by various forms of intelligent life! We can't really tell for sure what will happen!*