$$T = \frac{10^{10}}{\sqrt{t}} \quad {}^{o}\text{Kelvin}$$

$$E = \frac{860{,}000}{\sqrt{t}} \quad \text{eVolts}$$

T is the temperature in degrees Kelvin that was reached **t** seconds after the Big Bang.

E is the energy in electron Volts that was reached **t** seconds after the Big Bang.

Moments after the Big Bang, the universe was brilliantly hot, but steadily cooled with every passing second. All of the matter we see around us today was once fragmented into its individual parts, and we can re-create many of the original Big Bang conditions in our laboratories today. All we have to do is heat up matter so that the parts collide with the same energy as they would have during the Big Bang.

Physicists do this by using 'atom smashers' that accelerate individual particles such as electrons and protons, and then collide them. Thanks to Relativity, and Einstein's famous equation $E = mc^2$, all of the energy of the collision is then available for creating new kinds of particles…if they exist.

Astronomers can also use the Big Bang model to calculate at exactly what time after the Big Bang particles of matter typically had the energies being explored under laboratory conditions. There are two different formula, depending on whether you want to predict the temperature of the gas, or the average energy of the particles in the gas, as shown on the left.

Problem 1 - At 100 seconds after the Big Bang, what was the temperature of the universe, and what was the average collision energy, in kilovolts, of the particles at that time?

Problem 2 - Collisions between particles with a combined energy of 2 billion Volts (2 GeV) can produce a pair of particles, one proton and one anti-proton, out of pure energy. How many seconds after the Big Bang were particles colliding with these energies?

Problem 3 - How hot did the Big Bang have to be in order for it to create particles as massive as a pair of Top Quarks (E = 175 GeV for one top quark), and how long after the Big Bang was this temperature achieved?

Problem 4 - The Large Hadron Collider at CERN in Switzerland was recently 'powered-up' and achieved collision energies of 1.2 TeV, with an ultimate goal of about 15 TeV when it is fully operational in 2010. If 1 TeV = 1 trillion electron Volts (1 Terra EV), A) how many seconds after the Big Bang will the LHC be able to explore the state of matter at the lower and upper energy limits achieved in 2009 and 2010? B) What will be the temperature of matter at these two times?

Problem 1 - At 100 seconds after the Big Bang, what was the temperature of the universe, and what was the average collision energy, in kilovolts, of the particles at that time?
Answer;
T = 10 billion / $(100)^{1/2}$ = 10 billion/10 = **1 billion K**.
E = 860,000 eV / $(100)^{1/2}$ = 860,000/10 = 86,000 eV or **86 kiloVolts**. (abbrev. 86 keV)

Problem 2 - Collisions between particles with a combined energy of 2 billion Volts (2 GeV) can produce a pair of particles, one proton and one anti-proton, out of pure energy. How many seconds after the Big Bang were particles colliding with these energies?

Answer: From the equation for E, we can solve it for t to get t = $(860{,}000/E)^2$ .Since E = 2,000,000,000 eV, we get t = $(860{,}000/2{,}000{,}000{,}000)^2$ = 0.00000018 seconds or **0.18 microseconds after the Big Bang**.

Problem 3 - How hot did the Big Bang have to be in order for it to create particles as massive as a pair of Top Quarks (E = 175 GeV for one top quark), and how long after the Big Bang was this temperature achieved?

Answer: E = 2 x 175 GeV = 350,000,000,000 eV. Then since t = $(860{,}000/E)^2$ we have
t = $(860{,}000 / 350{,}000{,}000{,}000)^2$ = 0.000000000006 seconds or **6.0 trillionths of a second** after the Big Bang (also written as 6 picoseconds). At this time, the temperature was T = 10^{10} K/$(6 \times 10^{-12}$ sec$)^{1/2}$ = **4.1×10^{15} Kelvin or 4,100 trillion degrees K**.

Problem 4 - The Large Hadron Collider at CERN in Switzerland was recently 'powered-up' and achieved collision energies of 1.2 TeV, with an ultimate goal of about 15 TeV when it is fully operational in 2010. If 1 TeV = 1 trillion electron Volts (1 Terra EV), A) how many seconds after the Big Bang will the LHC be able to explore the state of matter at the lower and upper energy limits achieved in 2009 and 2010? B) What will be the temperature of matter at these two times?

Answer: A) E = 1.2 TeV so t = $(860{,}000/1{,}200{,}000{,}000{,}000)^2$ = **5.1×10^{-13} seconds**
And for E = 15 TeV; $(860{,}000/15{,}000{,}000{,}000{,}000)^2$ = **3.3×10^{-15} seconds**
The temperature will be T = $10^{10}/(5.1 \times 10^{-13})^{1/2}$ = **1.4×10^{16} Kelvin**
And T = $10^{10}/(3.3 \times 10^{-15})^{1/2}$ = **1.7×10^{17} Kelvin**