**University of Chicago Essay**

How many piano tuners are there in Chicago? What is the total length of chalk used by UChicago professors in a year? How many pages of books are in the Regenstein Library? These questions are among a class of estimation problems named after University of Chicago physicist Enrico Fermi. Create your own Fermi estimation problem, give it your best answer, and show us how you got there. – Inspired by Malhar Manek, Class of 2028

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**To begin,** a compelling problem is essential. The first interesting ideathat comes to mind is estimating the quantity of entangled particles in the observable universe using the Fermi Method. The Fermi Method is designed for situations where quick estimations are needed without access to external resources.

**Iterations:** There were more than 10 attempts to calculate these numbers using various methods, most of which yielded only theoretical answers. The final and definite result is explained in this paper.

**Volume:** The volume of the observable universe can be measured by treating it as a sphere. However, the universe's rate of expansion is increasing, so I estimated the universe's radius as 20 billion years instead of the more accurate age 15 billion and used that as the radius of the observable universe.

Speed of light in m/s:

Speed of light in m/year:

Radius of the universe:

Volume of Universe =

To ensure accuracy, I had previously used two calculators and subtracted the results to confirm they match. When both gave the same number, the subtraction produced a remainder too large to process. Realizing my tools were not sufficient, I switched to Wolfram Alpha online Calculator.

**Density:** The vast empty intergalactic spaces constitute the average density of the universe. To calculate this number, I revisited one of my earlier ideas of using quantum CPUs as an analog for intergalactic space but now with a key difference. Instead of a modern quantum CPUs I used an old one. Early quantum computers were often compared to space in terms of variables like temperature, isolation, and more. This meant they could represent the density of deep space with reasonable accuracy. One of the first quantum computers used a two-atom solution and was housed in a cylinder with a radius of about 0.5 m and a height of about 2 m. Using these dimensions in the cylinder volume formula, gives a density of approximately 1.273 atoms per m³.

Cylinder Volume =

Density =

With the density finally determined, it was time to calculate the mass. This involved a simple multiplication of density and volume, resulting in 2.9E110 atoms in the observable universe.

Atoms in universe =

**Quantum:**

Knowing the number of atoms in the universe, I still needed to determine how many of them are entangled. Particles entangle and disentangle at a defined rate. Working under the assumption that the dominant means of entanglement is accomplished by photons, a photon traveling from one atom will entangle two particles. They disentangle when either atom encounters a non-uniform force. Across the observable universe, this rate is offset based on a particle's distance from various light sources of differing strengths. There are other factors at play, but none cause entanglement and disentanglement as dramatically, and therefore will be ignored in a Fermi solution.

The universe is exceptionally large, on a scale in which the logic of infinities can be applied. All cosmic oddities like supernova do not matter, as they average out. This leaves only the variable T, the time between photon interactions. T can be simplified as a representation of the particle being entangled or not. So, I needed an equation where if T equals zero, then the particle is entangled, and any other value means it is not entangled. This equation does that , where T differs for every iteration of the summation.

This equation accurately accounts for the number of entangled particles in the observable universe with one key flaw. It's not a numerical answer but a theoretical one. It's impossible to solve, the number is just too big to find with available tools. To obtain a numerical result I made it a range, it would be better but still doesn't really answer the question because it is not an exact answer (the range would look like 0 to 2.9E110 atoms or all the atoms in the universe).

Considering the number of photons a star emits, it's reasonable to assume the next photon is as close as possible behind the first photon. Using the plank value, the smallest distance possible, means that for this summation the range of T is from 0 to 1E-35.

Replacing incalculable formulas with percentage-based math yields two different answers.

#1 Expected Entanglement = Iterations × Probability = 1E-35(plank value acting as probability) \* 2.9E110 (atoms acting as iterations) = 2.9E75 entangled atoms in the universe.

#2 The previous answer is calculated for a discrete instance. If you measured over a period of a couple of seconds the amount of entanglement that happened in that period would be unimaginably higher, coming close to 100% or about 2.9E110 atoms entangled.

**Conclusion**: In attempting to estimate the number of entangled atoms in the observable universe, I approached the problem in the spirit of a true Fermi question. Initially, I found a theoretical answer, which did not feel satisfactory. I reworked the problem through several iterations until I found a definitive answer. This process stretched my estimation abilities in ways I rarely get to practice. Though my solution was far from perfect and perhaps overly complicated, I found the challenge of filling in the gaps in my understanding immensely enjoyable. I hope my connections and thought process surprised or intrigued anyone reading, as the path to the answer was as valuable as the answer itself.