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The Infinite vs. Finite Current Universe: Decay of the Uranium-238

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The overall abundance of U in the Earth's crust is about 4 ppm, and it is concentrated in many minerals. On average the abundance of U in meteorites is about 0.008 ppm. We know that Earth's and meteorite's U was produced by several processes and that metal was inherited by the Solar system. This (natural) uranium (U) is primarily composed of two radioactive isotopes: ^{238}U (99.3 %) and ^{235}U (0.07 %). ^{238}U has a half-time, $t_{1/2}$, of about 4.5 Gy.

Let us assume that in our laboratory there is a 1 kg rock sample containing 3 % of ^{238}U (or 0.14 gram-atom) = $0.14 \times 6.023 \times 10^{23}$ (Avogadro number) = 8.4×10^{22} of the ^{238}U atoms. Let us also assume that this rock is about the age of Earth. The half-time of ^{238}U atom $t_{1/2}$ is related to its decay constant by $\lambda = \ln 2/t_{1/2}$ (see below). ≈ 0.154 $(Gy)^{-1}$. This also means for one year, the probability that a particular ^{238}U would decay is 0.154×10^{-9} or 1 out of 6.5×10^{9} y. As noted above, our rock sample contains 8.4×10^{22} of the ^{238}U atoms. This means about 6.5×10^{9} of these atoms would decay in one year or about 1.5×10^{4} per minute.

According to current thinking, the Universe similar to today's was formed about 12.8 Gy or about one billion years after the Big Bang. Hence, the infinite Universe would be formed at that time or before. But these two possibilities sound rather peculiar. The possible alternative is that the Universe has always been infinite and static. However, consideration of this issue is out of the scope of this communication.

The most intriguing question in modern cosmology is probably whether the Universe is infinite or finite in space. If the current Universe is infinite there is a total infinite number of ^{238}U atoms, N_U, in it. If there is now an infinite number of galaxies then the energy of the Universe at and before its formation would be infinite, and the energy/matter (converted into energy) after the formation would be infinite.

The radioactive decay rate of a source equals the number $\mathcal{N}$ of identical radioactive atoms present in the source, multiplied by their characteristic radioactive decay constant λ

$$\text{Radioactive decay rate} = \lambda\mathcal{N}$$

where the decay constant λ has dimensions of units of 1/time. The constant λ is one of the most important characteristics of each radioactive nuclide: λ is essentially independent of all physical and chemical conditions (although there are a few exemptions). The numerical value of λ is the statistical probability of decay of each radioactive atom (per unit of time) in a population of identical atoms. The half-life of a radioactive atom, $t_{1/2}$, is related to its decay constant by

$$t_{1/2} = 0.693/\lambda.$$

The average or mean life of a set of identical nuclei is related to the decay constant

$$\tau = 1/\lambda \quad \dots (1)$$

or

$$\tau = 1.44\, t_{1/2} \dots (2).$$

It represents the average time between decays.

If the number of identical nuclei $\mathcal{N}$ is infinite then their decay constant $\lambda = 0$ and the average lifetime is non-defined.

As we noted above, if the current Universe is infinite there would be an infinite number of galaxies and hence the infinite number of planetary systems with the rocky planets having a crust with more or less ^{238}U compared with Earth's crust. In that case, there are two options. The first is that in every possible time interval, an infinite number of ^{238}U atoms would decay, so all these atoms in our sample would decay instantly. Another option, due to an infinite number of decaying ^{238}U atoms in the Universe, is that none of these atoms in our sample would decay. However, experimentally, we know that the Geiger-Müller counter would detect about several hundred counts per minute of our ^{238}U sample. {See also [1]}. Therefore, the measured average life of the ^{238}U atoms, τ (> 0), in our laboratory sample would imply that the Universe is probably finite. This implies that the above-mentioned energy before the Big Bang was finite and that the contents of energy/ordinary matter (converted into energy)[1] after the Big Bang event was finite as well as current energy/ ordinary matter (converted into energy).

Reference

[1] R. B. McFee, *EMS responds to uranium exposure*, https://www.jems.com/operations/ems-responds-uranium-exposure/.

[1] Excluding dark energy and dark matter.