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A2 3 Cosmic Cuisine

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Abstract

This paper explores the time taken for a turkey to be cooked with Cosmic Microwave Background Radiation (CMBR) at an epoch corresponding to oven temperatures. We found that this occurred when the Universe was 6×10^6 years old. Under a constant-power assumption for radiative heat transfer, the time taken for the turkey to reach safe eating temperatures was around 44 minutes and through an integrated model this was increased to 50 minutes.

Introduction

One of the main pieces of supporting evidence for a 'hot' Big Bang is the existence of CMBR. This isotropic field evolves over time, cooling due to the expansion of the Universe, and scales with cosmological redshift, z. At the current epoch, it has cooled to a temperature of ~ 2.7 K, but at some point in time, it would have been at temperatures comparable to cooking temperatures achieved by modern ovens. This paper explores cooking times of a 4 kg turkey in the ambient temperature of the ancient Universe, finding the cooking time from pure radiative heat transfer caused by subjecting the bird to CMBR photons.

Theory and Results

Temperature and Geometry Parameters - The typical oven temperature T_{surr} for cooking a medium turkey is 180 °C [1] ($\sim$ 450 K). For safe consumption, the temperature T_{final} must reach a minimum of 75 °C [2] ($\sim$ 350 K). We assume an initial temperature $T_{initial}$ consistent with fridges, at around 5 °C ($\sim$ 280 K). We model the bird as a perfect sphere. A 4 kg turkey requires oven dimensions of 22 cm (width) $\times$ 30 cm (length) $\times$ 15 cm (height) [3], so we assume a diameter is the average of these: the sum divided by 3, or $\frac{67}{3}$ cm ≈ 0.22 m. Given this, we use the standard area equation of a sphere, $4\pi r^2$, to find our working area of 0.15 m^2.

CMBR Age - To find the age of the Universe for the CMBR to act as an oven analogue, we use the scaling relation between temperature and cosmological redshift. That is

$$T(z) = T_0(1 + z), \quad (1)$$

where T_0 is the CMBR temperature at current epoch, and $T(z)$ is the temperature at cosmological redshift, z. By setting $T(z)$ to the equivalent recommended oven temperature, we find $z = 166$. At this redshift ($z < 3400$) the Universe had long since transitioned from radiation dominated to matter dominated. This is where the total energy density in the Universe of non-relativistic matter (dark and baryonic) exceeds that of radiation. Therefore, the scale factor, $a(t) = \frac{1}{1+z}$, is related to time by $a(t) \propto t^{2/3}$, and so

$$t(z) = t_0(1 + z)^{-3/2}, \quad (2)$$

where t_0 is the current age of the Universe, 1.4×10^{10} years [4]. Using our calculated z, we find the time of the Universe where the CMBR was 450 K, $t(z) \approx 6 \times 10^6$ years.

Cooking - The specific heat capacity c_p is assumed to be constant, at 2800 J kg^{-1} K^{-1} [5] and is treated as a perfect blackbody (emissivity $\varepsilon = 1$). If the turkey occupies a homogeneous and isotropic region of the Universe, the pressure of the vacuum is of orders close to 0 Pa. According to the Gibbs' phase rule, water cannot exist as a liquid under 600 Pa. At our temperatures (≥ 280 K) it would be gaseous [6]. A bare turkey means that the water inside would be lost, leaving a dry and inedible product. Addressing this, we assume an inert, gas-filled container at the same instantaneous temperature as the turkey, at an Earth-like local pressure, such that moisture is retained, which is large enough that increasing temperature does not cause a significant pressure spike. We also assume emissivity and radiative interactions are unchanged. The heat net energy Q absorbed by the turkey is

$$P_{\text{net}} = \frac{dQ}{dt} = \varepsilon \sigma A \left(T_{\text{surr}}^4 - T^4 \right), \qquad (3)$$

where σ is the Stefan-Boltzmann constant, t is time and T is the instantaneous temperature. In our initial conditions, this is equal to $T_{initial}$. Upon cooking, our target temperature is T_{final}. If a uniform power is assumed based on our initial parameters, then P_{net} is 300 W. The total cooking energy Q_{tot} can be found with

$$Q_{tot} = Mc_p(T_{final} - T_{initial}). \qquad (4)$$

That is 780000 J. With this, the time from dividing Q_{tot} by P_{net} is 2600 s, or 44 minutes. Equation (3) shows that the power decreases as the turkey heats up; it edges towards thermal equilibrium. Therefore, to improve this model, we consider each incremental 'step':

$$dQ = Mc_p \, dT. \qquad (5)$$

We couple this with P_{net} to find the relationship

$$dT = \frac{\varepsilon \sigma A}{Mc_p \left(T_{\text{surr}}^4 - T^4 \right)} \, dt = \frac{P_{net}}{Mc_p} \, dt. \qquad (6)$$

This is then numerically integrated using small time steps dt to update dT over a while loop, which then replaces T and therefore P_{net} as they vary over time. This loop terminates when T reaches T_{final} and prints the corresponding elapsed time. At a time step of a second, the turkey reaches the target temperature at 3003 s, or 50 minutes.

Discussions and Conclusion

As expected, our integrated solution is higher as net radiative flux decreases as the turkey nears thermal equilibrium. This can be seen in Figure 1, the temperature gradient slightly plateaus as it increases.

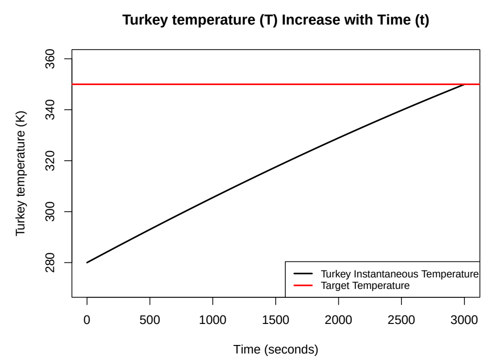

Figure 1: Integrated method of heating with time

While success is found in the radiative heating model, there are limitations. An example is the container. The gas inside had to be transparent to incoming radiation for heat transfer to be purely radiative, ignoring conductive and convective effects. These effects would reduce cooking time, especially at Earth-like pressures. Also, turkeys do not have a uniform heat capacity, differing by bones, fats, and tissues. This difference is more pronounced during heating as proteins denature and fats melt. To conclude, we found that at 450 K, the Universe was at an age of 6 million years and a 4 kg turkey would reach eating temperatures in 50 minutes. Improvements include consideration of conductive and convective effects and temperature gradients caused by physical variations in the turkey.

References

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