Thermalization, the Universe’s Balancing Act Between Baryonic Matter and Radiation

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Any plausible story will hold until the truth be told.

Any material system comprised of baryonic matter at a temperature above absolute zero will involve the interaction of photons of radiation and particulate matter. These interactions involve the emission and subsequent absorption of photons transmitted between material components of the system. It is this process that ultimately brings a system into equilibrium, in which state all component groups within the system share the total energy equally. The blackbody form of the cosmic microwave background (CMB) provides evidence that the universe is such a system. This CMB radiation is known to have a radiation temperature T_{rad} of 2.728 K and its energy density is 4.169×10^{-13} ergs/cm^3. However, the kinetic temperature T_k of the universe is not now, it never was, nor ever will be 2.728 K (minus 460 degrees Fahrenheit), even though that is what we are repeatedly told by cosmologists. It's over 3,000 degrees K *now* – not just at an earlier epoch when cosmologists insist that the temperature was ‘frozen in’ at a redshift of 1,200.

That there is a ‘chill’ to the universe does not imply a low kinetic temperature T_k, a parameter that reflects the speed of the constituent particles of a system. It is a fact that kinetic temperature is not 'heat'; they are proportional but not equal. Heat is an indication of the internal energy density of a system. The density of baryons times kinetic temperature that encompasses their masses and velocities are what constitute a system’s kinetic energy density ρ_k and that thereby comprises heat.

$$\rho_k = (3/2)\, k\, \rho_e\, T_k$$

Here $k = 1.38 \times 10^{-16}$ ergs/K is the Boltzmann constant. Thus, a dense system of particles will be much hotter than one that is sparse even if the distributions of their masses and velocities and therefore their kinetic temperatures, are the same.

The internal energy of a thermodynamic system in equilibrium is shared equally among its constituent classes. Equipartition applies to energy, not temperature, although it applies to kinetic temperatures of multiple classes of particles since the other two aspects of their kinetic energy are constant. It also applies to associated emitted radiation energy, which is a surface brightness phenomena transformed into an energy density ρ_{rad} by integrating Planck’s blackbody formula over all wavelengths to obtain Stefan’s formula and then dividing that by the speed of light.

$$\rho_{rad} = 7.56 \times 10^{-15}\, T_{rad}^4$$

However, $T_{rad} = T_k$ only applies to observed radiation if there is no redshift occurring between the emission and observation of the radiation. The impact of redshift on radiation is described by Wien’s law that relates the radiation temperature to the kinetic temperature as follows:

$$T_{rad} = T_k / (Z+1)$$

So, yes, the kinetic and radiation (CMB) energy densities are the same – not the temperatures.

Standard cosmological model proponents (virtually all current cosmologists) apply Wien’s formula to conjecture that emission of the CMB (virtually *all* of it) took place at an earlier epoch in an expanding universe (at a redshift Z of about 1,200) when the kinetic temperature T_k of the universe had been about 3,300 K. Thus, they dry-lab the result: $T_{rad} = 3{,}273.6 / 1{,}200 = 2.728$ K. This would coincidentally terminate the universe as a thermodynamic system in equilibrium; this would have had to have happened about 380,000 years after a 'big bang' out of which they contend our universe sprang. They propound that at this juncture, the decreasing energy density caused virtually all free plasma electrons to be captured by positive protons and alpha particles, thus becoming neutral hydrogen and helium. Gravity would naturally have long since caused these neutral particles to coalesce, ultimately into the stellar, galactic, and galactic cluster structures we now see. Some subsequent ionization would have taken place due to resulting hydrostatic pressure. The vast expanding spaces between structures would, they claim, be essentially cleared of radiation emissions and scattering. So the radiation observed as the CMB would virtually all have been emitted over 13 billion years ago when its kinetic energy density ρ_k was not the current 4.169×10^{-13} ergs/cm^3, but larger by a factor of over 2×10^{12}. Stefan's and Wien's formulas quantify the conjecture to obtain $\rho_{rad} = 4.169 \times 10^{-13}$.

That's one story but not *the* story. Some of the harder parts to accept are the expansion and *creatio ex nihilo* upon which it is based.

A much more compelling story maintains that the energy density of the universe (both particulate and radiational) have not changed over cosmological time intervals and distances. The universe is the same uninterrupted thermodynamic system in equilibrium it has always been. The current properties of the CMB must be embraced as realities, but this story also acknowledges currently observed properties of the baryonic material universe as equally factual thermodynamic quantities rather than just ignoring them or otherwise incongruously rationalizing them as being thermodynamically inconsequential. However sparse, the intergalactic hydrogenous plasma exceeds in mass all the rest of the baryonic matter in the universe both now and in all past epochs. Unlike the standard model that presumed instantaneous complete uniformity of thermodynamic quantities up until a redshift of 1,200 at which time uniformity ceased altogether. In this story, the universe is not now, and never was, completely uniform in baryon density and temperature. But the averages over cosmological regions of space and time are indeed uniform.

Brackets "$<x>$" are employed to indicate that the bracketed quantity x is averaged over all space. The mean baryonic mass density is $<\rho_m> = 4.2 \times 10^{-31}$ g cm^{-3} (roughly 5% of Einstein's critical density). The number density $<\rho_e>$ of baryons is determined by taking the ratio $<\rho_m>/<m_p>$, where $m_p = 1.66 \times 10^{-24}$ g is the representative mass of a baryon, most typically a proton. In addition, there is an electron associated with each such baryon.

$<\rho_e> = 2.5 \times 10^{-7}$ cm^{-3}

The average kinetic energy density $<\rho_k> = 4.169 \times 10^{-13}$ ergs/cm^3 must be the same as that of the radiation, i.e., $<\rho_{rad}> = \rho_{CMB}$. The functionalities that gives rise to these values are the following:

$<\rho_k> = (3/2)\, k <\rho_e|T_k>$

$<\rho_{rad}> = 7.56 \times 10^{-15}\, T_{rad}^4$

Here $<\rho_e|T_k>$ is a unique parameter proportional also to average pressure. It is an average of a product which is very different from the product of the separately averaged parameters whenever the two parameters experience considerable independent variation as is the case with ρ_e and T_k in galaxy cluster cells that are representative units of the universe itself.

In embracing the apparent perpetuity of equal energy densities of baryonic and radiational constituents of the universe, one must address the properties of observed radiation as having been emitted from every depth in space. This particularly applies when densities are low enough that radiation 'sneaks in' between the local baryonic matter. And even though we assume uniformity of the average kinetic temperature $\langle T_k \rangle$, there is redshifting that takes place when radiation from more remote regions is included in the currently observed distribution. Assessment of the average redshift experienced requires consideration of the distribution of material entities in space that gives rise to the distribution of radiation in redshift which is the blackbody CMB.

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It is noteworthy that even though they are equal, the energy density of radiation unlike its particulate counterpart, does not involve the density of baryonic matter. Thermal radiation energy density is a surface brightness phenomenon. Historically the term 'blackbody' radiation got its name from laboratory equipment used to measure thermal radiation from heated cavities. Within the cavity walls, photons of various frequencies permeate the space, being absorbed and re-emitted either by free particles or more probably in smaller containment, the atoms at the surface of the wall itself. Virtually all photons originate and terminate on the inner surface of such a container – certainly not from beyond the complete 'sky cover' provided by that container. In his precise formulation Planck posited 'oscillators' with distinct resonance frequencies at the inner cavity wall responsible for emission and absorption of individual 'quanta' of radiation.

Despite proponents of the standard cosmological model insisting on a 'surface of last scattering' to provide a complete 'sky cover' surface, there is no such neat and clean cavity wall to the universe. But there is complete sky cover S(r) that is filled in from dispersed baryonic matter at increasing depths r in space. Lines of sight of radiation from baryonic matter in distant regions of space either reach the observer with an associated redshift or are intercepted by baryonic matter in the interval, contributing to the ambient internal heat of matter at that distance. So at each distance interval there is a decreasing number of emitting particles of matter where lines of sight terminate, but they gradually fill in to provide a total sky cover. The amount of this total sky cover contributed at each distance r depends on the number of such particles in that interval, which depends in turn on the depth of the interval, uniform number density of particles in the universe, and the cross-sectional area of those particles. The average baryonic number density $\langle \rho_e \rangle$ of these, primarily hydrogen atoms – whether neutral or ionized with free electrons – is accepted as being somewhere around 10^{-7} per cubic centimeter, so we begin with $\langle \rho_e \rangle \approx 10^{-7}\ \text{cm}^{-3}$. The average cross-sectional areas σ of these ions is on the order of $6.6 \times 10^{-25}\ \text{cm}^2$.

The derivation and demonstration of formulas for the diminishing portions of sky cover dS(r) encountered at each distance is documented in sparate article on this site. The result is:

$$dS(r) = \eta\, e^{-\eta r}\, dr.$$

Here $\eta = \langle \rho_e \rangle\, \sigma \cong 6.6 \times 10^{-32}$.

The total sky cover S(r) out to the distance r is the integral of dS(r). To determine the average redshift of observed background radiation, one must integrate over all space (to infinity in the limit) to obtain the average redshift experienced by the thermal background radiation of the universe. The integrand is mitigated by dS(r) as a weighting factor in the averaging process as follows.

$$<<T_k>/(Z+1)> = \int_o^\infty (<T_k>/(Z(r)+1))\, dS(r) = \int_o^\infty <T_k>\, \eta\, e^{-(\eta+H_o)\, r}\, dr = <T_k> / (H_o/\eta+1)$$

$$= <T_k> / (1+1.11 \times 10^3)$$

Thus, the average redshift of the CMB is indeed about 1,100, but that value has a very different and additional implications from an instantaneous situation in an expanding universe. Also, the temperature of over 3,000 K is not an instantaneous value; it is an average throughout the universe.

We have used $Z(r)+1 = e^{-H_o r}$ in the integrand, a frequently used approximation for the standard cosmological model but a precise expression for the alternative model advocated by the author. This is explained in detail in the paper 'Edwin Hubble's Discovery' available on this site. $H_o = 7.3 \times 10^{-29}$ cm^{-1} is a currently accepted value for Hubble's constant in the relevant (one over distance) units. We incorporate contributions of the kinetic temperature to radiation energy density from all portions of the sky cover to obtain:

$$\rho_{rad} = 7.56 \times 10^{-15} < <T_k> / Z+1>)^4 = 4.169 \times 10^{-13} \text{ ergs/cm}^3$$

This ultimately explains why the temperature of the universe's blackbody radiation distribution – the CMB – differs so dramatically from its kinetic temperature without a parody of Genesis I.

The universe is indeed a thermodynamic system in a stationary state. It is not a static, nor yet a 'steady state' universe – but one that continually churns under the hydrostatic pressures of gravitational collapse and thermodynamic resistance in galaxy cluster cells maintains its universal equilibrium. Its characteristics are the following:

$<\rho_m> = 4.175 \times 10^{-31}$ g cm^{-3}	*universal average baryonic mass density*
$<\rho_e> \approx 2.5 \times 10^{-7}$ cm^{-3}	*universal average baryon density*
$<T_k> = 3{,}120$ K	*universal average kinetic temperature*
$<\rho_k> = 4.169 \times 10^{-13}$ ergs cm^{-3}	*universal average kinetic energy density*
$<P_k> = 2.779 \times 10^{-13}$	*universal average plasma pressure*
$<\rho_e \vert T_k> = 2{,}014$	*universal average cosmological redshift parameter*
$<\rho_{rad}> = 4.169 \times 10^{-13}$ ergs cm^{-3}	*universal average radiation energy density*
$T_{rad} = 2.728$ K	*universal average radiation temperature (CMB)*

<Z> = 1,143 *universal average radiation redshift*

These are not written in stone, but they are warranted as reasonable approximations. Those that are not direct measurements are warranted by analyses presented in this and other papers as well as the volume Cosmological effects of Scattering in the Intergalactic Medium available on this site.