protons. These exist in one of two states, either free as hydrogen, or bound into collections such as helium, carbon, and the rest of the elements. Cosmic equilibrium dictates a constant rate of creation and destruction for both of these proton configurations, so there are two universal energy cycles - the *fusion cycle* and the *annihilation cycle*:

Ψ THEOREM 14.2 - UNIVERSAL ENERGY CYCLES {Ψ14.1}

THERE ARE TWO UNIVERSAL ENERGY CYCLES:

(A) FUSION CYCLE: BOUND COLLECTIONS OF PROTONS

(B) ANNIHILATION CYCLE: FREE PROTONS

Although annihilation and fusion exist in any high-energy environment, such as the interaction between cosmic rays and interstellar material, the cycles noted above represent the large-scale processes responsible for the genesis and overall density of the *majority* of the universe's material. Atomic nuclei containing more than one proton will be referred to as *compound nuclei*.

14.5 FUSION CYCLE

The fusion cycle is the balance between hydrogen and compound nuclei. Our telescopes and space probes have revealed the leading players on the celestial stage, so this cycle's rough outline is already available:

(hydrogen fuses) → (compound nuclei, light) →
(light loses energy by intergalactic redshift, scattering, absorption) ?→
(CMB) ?→ (nuclear dissolution occurs to produce hydrogen) ?

The majority of the luminous energy released by this cycle is from hydrogen fusion, but there is also a small contribution from the fusion of helium and heavier nuclei. The universe is full of galaxies that are in turn composed of stars. They burn hydrogen to produce helium, heavier elements, and light. Fusion is responsible for the universal optical and infrared luminosity densities. The light released by fusion loses its energy through the intergalactic redshift, scattering, and absorption.

Current measurements indicate that photons lose about half of their energy after a journey of ten billion light years through deep space. *This means every ten billion years, half of the universe's entire luminous output is lost to redshift*. Where does all of this energy go? The energy is lost in intergalactic space. The only known energy radiating from deep space is the CMB. Since the CMB is essentially a source of energy emanating from everywhere in deep space it is reasonable to think that it is the direct or indirect by-product of intergalactic redshift.

This is why it is included in the above sequence. The CMB carries energy until such time as it can be used to break down the elements that fusion forms in order to release hydrogen and complete the cosmic process. This is the *fusion cycle*.

Stars have been burning hydrogen forever and require an endless, renewable supply. The amount of energy in the universe does not change over time, so the only possible source of new hydrogen fuel *is the nuclei formed during fusion*. All forms of matter are recyclable - the first law of cosmostasis. This requires *reversibility* in any formative process. The energy in the light released by the fusion of protons must eventually be used to break them apart.

The overwhelming majority of the universe's power output is fusion, predominantly hydrogen fusion. The fusion of helium into carbon, for instance, only produces about 4% as much energy per unit mass as hydrogen fusion. A great deal of energy is released by supernovae, but this is negligible compared to the power generated by main sequence stars over the course of their enormous lifespans. In general, the fusion cycle will refer to all types of fusion, but hydrogen fusion is the first step. Without it there is no helium or carbon fusion:

Ψ THEOREM 14.3 - FUSION CYCLE FUEL {Ψ14.1}

HYDROGEN IS THE FUEL FOR THE FUSION CYCLE

Hydrogen fusion drives the universe's primary energy transfer and will be defined as the fusion cycle's beginning point. The mass fraction of hydrogen fusion, ε, is 0.0073. This is the fraction of mass converted into energy when helium is formed. The term ε_U will be used to denote the energy-averaged mass fraction of all fusion reactions in the universe, from the controlled, slow burning of hydrogen to the catastrophic formation of carbon and iron in supernovae. Since hydrogen fusion produces the lion's share of the cosmic engine's output, ε_U is close to ε. This approximation is more than sufficiently accurate for our calculations in Part IV, given the limited resolution available in the known universal parameters.

§ DEFINITION 14.1 - UNIVERSAL MASS FRACTION

THE UNIVERSALLY AVERAGED MASS FRACTION OF ALL FORMS OF FUSION IS $\varepsilon_U \approx \varepsilon$

The fusion cycle begins with the production of compound nuclei and light. It ends when these recombine and compound nuclei are converted back into hydrogen. This cycle could also be termed the *mass-fraction cycle* or the *binding energy cycle* because its two functions are to bind protons, converting part of their mass into light energy, and then use the energy originally released as light to disassociate nuclei back into individual protons, thereby replacing their lost mass and creating an endless source of hydrogen.