Adiabatic Expansion of the Universe

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Abstract

The expansion of the universe is proved to be an adiabatic process. The proposed idea shows good agreement with the observable universe and can explain some basic characteristics of the universe. It is also showed that the first kind of Friedmann model contradicts with the observable universe. The proposed idea also indicates that the size of the universe is finite.

1. Introduction

The discovery that the universe is expanding was one of the great intellectual revolutions of the twentieth century. The red shifted spectra of stars in distant galaxies, observed by Edwin Hubble, revealed the fact that the galaxies are moving rapidly away from us. Hubble's observations suggested that the current expanding universe resulted from a singularity called the Big Bang. At that time, the density of the universe and the curvature of space-time would have been infinite. Big Bang model is the generally accepted theory for the origin of the universe.

There are many theories that explain the nature of the expansion of the universe. If the expansion rate of the universe is sufficiently slow, then the gravitational attraction will eventually cause it to stop expanding and start contracting. This is called the first kind of Friedmann model (proposed by Alexander Friedmann) [1]. Other theories state that the universe is expanding fast enough to avoid re-collapse, indicating that the universe will expand forever.

In this work, a thermodynamic approach is used to show that the first kind of Friedmann model does not agree with the observable universe. Then it is proved that the temperature of the universe is an inverse function of the expansion of the universe, which indicates that the size of the universe cannot be infinite.

2. Universe as an Isolated System

In the early universe, the objects would have been very close to each other [2] i.e. the universe was infinitesimally small. It would have started off with a period of exponential expansion in which it would have increased its size by a very large factor. But still it is not absurd to imagine universe has a *boundary* since it started its journey from zero size.

This boundary is indirectly defined by the law of conservation of energy. Within this boundary the total energy remains conserved and equals to zero [1]. No energy "goes out" or "comes in" through this boundary.

Thus the universe can be imagined as an isolated system which is expanding, as shown in Fig. 1. A good analogy to this idea is an ideally insulated cylinder containing certain amount of ideal gas. The piston of the cylinder can be moved to expand the volume of the gas. Due to the insulation, the gas molecules cannot give up energy outside the cylinder and no energy from outside enters the cylinder, so the overall energy of the gas molecules remains constant although not zero.

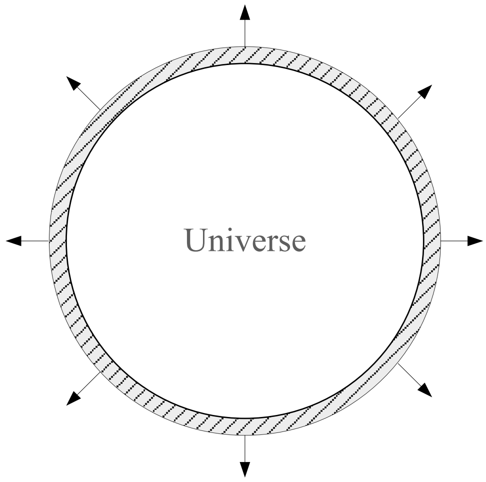

Figure 1. Universe imagined as an expanding closed system.

3. Adiabatic Expansion of the Universe

To understand the idea that the expansion of the universe is an adiabatic process, some basic characteristics of the observable universe need to be discussed. The law of conservation of energy is an empirical law of physics. It states that the total energy of the universe remains constant over time [3]. A consequence of this law is that energy can neither be created nor destroyed; it can only be transformed from one state to another. Albert Einstein's theory of relativity shows that energy and mass are the same thing and that neither one appears without the other. Thus in an isolated system, both mass and energy are conserved separately.

The second characteristic that needs to be considered is the temperature of the universe. At about one hundredth second after the big bang, the temperature of the universe was about a hundred thousand million degrees Centigrade. As the explosion continued, the temperature dropped, reaching thirty thousand million Centigrade after about one-tenth of a second, ten thousand million after about one second and three thousand million degrees after about fourteen seconds [2].

The expanding universe is filled with a universal background of radiation which appears to be left over when the universe was thousand times smaller and hotter than at present. The radiation is considered to be expanding freely i.e. the wavelength of each photon would have stretched out in proportion to the size of the universe, as the universe expanded. Since the average wavelength of black-body radiation is inversely proportional to its temperature, the temperature would have decreased in inverse proportion to the size of the universe. So the study of cosmic microwave background radiation undoubtedly states that the temperature of the universe is decreasing with the expansion of the universe.

From the above discussion, a conclusion can be made that the universe is an isolated system, in which total energy is conserved and it is expanding with time and cooling inversely proportional to its size. Now all these characteristics clearly state that the expansion of the universe is an adiabatic process.

Again the analogy of a well insulated cylinder can make the idea more understandable. If we move the piston to allow the expansion of the volume of the gas inside the cylinder, the temperature of the gas will fall. Since the walls of the cylinder are insulated, no energy of gas flows through the wall outside the cylinder. This is the definition of an adiabatic expansion.

4. Entropy of the Universe

The idea that the expansion of the universe is an adiabatic process may answer some contradictory theories. In 1922, Alexander Friedmann made two very simple assumptions that the universe looks identical irrespective of the direction of observation and this would be true if the universe is observed from elsewhere [1].

There are three different kinds of models that obey Friedmann's two fundamental assumptions. In the first kind, the universe is expanding fairly slowly that the gravitational attraction causes the expansion to stop and eventually to contract. In the second kind, the universe is expanding so rapidly that the gravity can never stop it. Finally, the third kind states that the universe is expanding just fast enough to avoid the re-collapse.

The first kind of Friedmann model states that the expansion of the universe is a reversible process. If the expansion of the universe is considered to be an adiabatic process, this would mean that the entropy or degree of disorder of the universe is constant, which certainly does not agree with the observable universe. In this case, there would be no well-defined *thermodynamic arrow of time*. So it is logical to say that the idea that the universe will stop expanding and start contracting someday is not right.

Other two kinds of Friedmann model state that the expansion of the universe is an irreversible process. Adiabatic processes are characterized by an increase in entropy if they are irreversible [4]. If the expansion of the universe is considered as an irreversible adiabatic process, there remains no contradiction with the observable universe.

Moreover, the theory that the expansion of the universe is an adiabatic process explains the fact that the temperature of the universe decreases in inverse proportion to the size of the universe. For an adiabatic process, the relation between volume and temperature is given by

$$T\,V^{\gamma-1} = constant \tag{1}$$

where, T is the temperature, V is the volume and $\gamma = {}^{C_P}/_{C_V}$ is the adiabatic index. Here, C_P is the specific heat for constant pressure and C_V is the specific heat for constant volume. If we use this equation for the universe, it is clear that the temperature of the universe (T) is inversely proportional to the size of the universe (V).

$$T \propto {}^{1}/_{V^{\gamma-1}} \tag{2}$$

5. Size of the Universe

A remarkable feature of the first kind of Friedmann model is that the universe is not infinite in space. Space is bent on itself like the surface of the earth and therefore is finite in extent. In the second model, the space is bent in the other way like the surface of a saddle and in the third model, space is flat. So space is infinite according to second and third model [1].

Now this may introduce confusion since the size of the universe was assumed to be finite in order to prove the first kind of Friedmann model wrong. According to the second and third kind of Friedmann model, the universe will expand forever. But this does not mean that the size of the universe is infinite now. Size of the universe could be a very large finite number. This can be proved easily with the help of (1).

The expression (1) indicates that the size of the universe will be infinite when the temperature of the universe reaches absolute zero. According to cosmic background radiation measurements, the temperature of the universe is around 2.7281 Kelvin, which is above absolute zero [5]. This value yields a finite but very large size of the present universe.

6. Conclusion

The idea of adiabatic expansion of the universe agrees well with the observable universe. Empirical laws of physics and experimental facts both support this idea. With the help of this idea, a relation between temperature of the universe and time elapsed after the Big Bang can be derived, which will be subject of a future paper.

References

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