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On the Arrow of Time

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Abstract

The arrow of time is one of the most difficult questions in modern physics. In this paper, a damping vibration equation is discussed, which shows that this equation reflects the arrow of time. We have further discussed that the concept of "the arrow of time" in this equation is quite different from the thermodynamic arrow.

Keywords

The Arrow of Time, Damping Vibration, Friction

1. Introduction

"The arrow of time" has become a popular topic in modern physics. This word, "the arrow of time", is first proposed by British astrophysicist Arthur Eddington in 1927. The research for the grand unified theory is forcing physicists to revisit some very basic assumptions, such as time, because "time" in physics is a basic physical quantity [1].

The issue of time in physics has been discussed in many papers and books, such as [2]-[5]. However, "time" is still one of mysteries in science, although many scientists have studied it for long time. In many physical theories, "time" shows no direction. In addition to thermodynamics, the variable of time in differential equations to describe the physical laws seems reversible. Obviously, there are huge differences between the time in physics and the time that people feel. In the community of theoretical physics, many scientists believe that time does not exist.

In fact, scientists usually consider the ideal case of a single particle motion in terms of differential equations. They are able to solve the problem of the two-body motion. However, for multi-body motion, we can hardly obtain solutions, which are beyond of our mathematical ability.

Indeed, time represents the natural sequence of events of various objectives. As for how to quantitatively measure the time, it is artificial and relative. In the applied physics and everyday life, people take a variety of definitions of time. By using the atomic clocks, it only improves the accuracy of the relative time, and it does

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not change the nature of time.

It is a foundation of science that time is one-way direction. The law of causality is based on a very large number of experiments. This should be an axiom. However, many physicists do not recognize this fact, and then it causes confusion in modern theoretical physics.

2. The Damping Vibration Equation

Most physical processes in nature are irreversible. On the other hands, the basic equations of physics contain almost no "arrow of time". These equations in physics show the "ideal case". However, when we consider the real problem, it is not enough to use these equations only. We have to add some correction terms to make it realistic.

To specify the issue of "the arrow of time", we first examine the ideal vibration equation, which is a pendulum with simple harmonic motion:

$$F = \mathrm{d}^2 x / \mathrm{d}t^2 = -kx \tag{1}$$

From (1), we can get the mathematical solution of a periodic motion:

$$x = A\cos(\omega_0 t + \phi) \tag{2}$$

here, A is the amplitude of the pendulum, φ is the phase angle, and the natural frequency is:

$$\omega_0 = \sqrt{k/m}$$

In Equation (1) and its exact solution (2), the swing amplitude A is a constant, and the time variable t can be positive or negative.

In practical cases, the pendulum motion experiences air resistance, and then the swing amplitude decreases with time. To describe this physical process, one needs to add a damping term into the right-handed side of Equation (1), which is proportional to the speed of the pendulum. Then we have the following equation of motion:

$$m\frac{\mathrm{d}^2 x}{\mathrm{d}t^2} = -kx - \gamma\frac{\mathrm{d}x}{\mathrm{d}t} \tag{3}$$

By introducing the damping factor, $\beta = \gamma/2m$, it represents the nature of the vibration system interacting with the media. In small damping conditions: $\beta < \omega_0$, the solution of Equation (3) is:

$$x = A_0\,\mathrm{e}^{-\beta t}\cos(\omega' t + \phi_0') \tag{4}$$

where $\omega' = \sqrt{\omega_0^2 - \beta^2}$; A_0 and ϕ' are the integral constants determined by the initial conditions.

The cosine term in the above equation shows the periodic motion. $A_0\,\mathrm{e}^{-\beta t}$ expresses the exponential decay of the amplitude, which reflects the influence of damping effect. We notice that in this exact solution, the time variable t can only take positive. On the other hands, if the time variable t takes a negative value, the swing amplitude would increase with time. That would be against the experimental facts. Therefore, the motion of a damping pendulum, Equation (3), reflects the arrow of time.

3. Some Discussions about the Arrow of Time

As mentioned in the above section, Equation (3) is a simple example to show "the arrow of time" by mathematical formula.

In macroscopic situations, because there exists always friction and dielectric resistance in real world, the amplitude of a pendulum will gradually decrease towards zero. However, in microscopic world, there is no absolute stationary case.

Here we discuss some related issues.

1) An object surrounding by thin medium is a common phenomenon in nature, for example, a rock is "aging" by the long-term wind, and ends as sands. Indeed, this complex phenomenon is hardly represented mathematically.

2) Concerning the nature of friction, people have not understood it very clearly. Most scholars believe that friction is the interaction between molecules at two contacting surfaces. It involves complex physical and chemical interactions between molecules. These interactions cannot simply be attributed to the thermodynamic problem.

3) The second law of thermodynamics is also known as the principle of entropy increase, *i.e*. the thermodynamic arrow. The applicable conditions of the second law of thermodynamics are: a) for a system containing large number of molecules; b) it applies to an isolated system, in which the natural process is always carried out along the direction of increasing entropy.

4) The phenomena of "dissipation", "friction" and other such physical (and chemical) effects are widespread in real world. Thus the evolution of physical phenomena has the positive direction. In another word, the direction of time in nature is closely linked to the phenomena of "dissipation". As a result, the physical phenomena in nature show the arrow of time.

In the real world, there is no such closed system strictly. For example, the neutrino can easily pass through the Earth. In an open system, an object surrounding by thin medium is exerted by dissipative force, which is a common phenomenon in nature. Since an object exchanging its matter and energy with the outside medium, it is a complex physical and chemical process between microscopic particles. This objective process is irreversible, and it is the source of "the arrow of time".

From the above analysis of a pendulum motion, one can clearly see that there are two kinds of typical solutions: 1) In deal case, the pendulum motion without the damping term has no "the arrow of time"; its advantage is to show the stable period for time measurement; 2) In the real world, there are the damping effects for the pendulum motion, which reflects "the arrow of time".

In more general situation, "the arrow of time" also exists in nature, for example, the wave packet always diverges over time.

The above analysis is valid for the microscopic world as well. In the existing theories, physics of the time at the microscopic level is almost symmetrical, which means that the laws of physics still hold when taking the time reversal. However, similar to the pendulum motion without damping, the effect of "vacuum" is not considered in these cases. In fact, the "vacuum" is generally recognized as a kind of quantum field, or quantum "media" in modern physics. From experiments, the "vacuum fluctuations" has been discovered. Therefore, similar to the previous case with macroscopic dissipative force in the above section, "the arrow of time" should also exist in the microscopic world.

Obviously, "the arrow of time" should be a foundation of science. The law of causality is based on a very large number of experiments. If the law of causality does not hold, then all the natural sciences will be tumbling down. In another word, the law of causality is a foundation of science, which is more important than any single equation in physics.

General speaking, in most physical equations, the ideal case for the motion of individual particle is considered in nowadays. These equations present only approximate description of the real world. In the multi-body motion and complex motion, "the arrow of time" represents the law of nature.

In short, "the arrow of time" and the scientific meaning of time deserve more extensive discussion in modern physics, and it has significance for the development of physics in future.

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