Chapter 3: Space

What is space? The original meaning of the word is an empty space, a place where no objects exist. However, in physics, it is considered a place where objects exist and natural phenomena occur. Alternatively, it is often used interchangeably with the coordinate system that describes position. In classical mechanics, space was considered an entirely independent entity, separate from objects and time, a container for objects, and a three-dimensional space as conceived by Euclid. However, since the quantities of physics should be determined based on natural phenomena, the properties of space in physics should be determined by its relationship to the physical laws applied to the natural phenomena occurring within that space. If we consider it this way, we cannot assume that space is an entity independent of objects and time.

Initially, I intended to discuss important concepts in physics regarding the understanding of space, such as the principle of relativity and inertial coordinate systems, in this chapter. However, I decided that it would be more appropriate to address these topics in a separate chapter, and therefore, I have moved them to the next chapter.

In this chapter, rather than tackling the complex question of what space is, let's simply consider how distance is measured in physics.

3.1 Method of measuring distance

Methods for measuring distance can be broadly categorized into the following three types.

(1) Methods using the motion of objects

How can we measure distance? As everyone knows, for example, we can use a stick and count the lengths. If we arbitrarily choose an object of some reference length, assume that its length does not change, and count how many times longer the object is

than that, we can measure the distance. This reference length could be, for example, 1 meter.

For example, if you want to measure a length of 10m with a 1m rod, you would have to repeat the measurement with the 1m rod 10 times. Whether you take 30 seconds or 20 seconds to do this, you will still measure a length of 10m, and at first glance, it seems that there is no relationship between distance measurement and time. However, this task certainly requires time, and repeating the measurement with a 1m rod 10 times can be considered equivalent to rotating a circle with an outer circumference of 1m 10 times. Therefore, the difference in measurement time is represented by the difference in rotation speed.

(2) A method using the relationship distance = speed × time

Another method for determining the distance traveled by an object moving at a constant speed is to determine the distance traveled from the time taken. For example, if we assume that the speed of light is constant, then the distance traveled by the light and the time taken are proportional. The modern definition of the length of 1 meter is that "1 meter is the length of the path that light travels in a vacuum in 1/299792458 of a second," and this definition uses the relationship distance = speed × time.

The meter was first internationally defined in 1889, with the length of the platinum-iridium international meter prototype being defined as the unit of length. However, the length of an object is not fixed; it can easily change due to temperature changes, for example. Since a standard for length that changes easily is unreliable, this definition was later changed to one that uses the speed of light.

This method is suitable for measuring relatively long distances with relatively high accuracy.

(3) Method using apparent angles

Distance can also be measured using a method known as triangulation. This method applies Euclidean geometry to calculate distance from the relationship between the sides and angles of a triangle.It is empirically known that the distances measured by this method are equal when either method (1) or (2) can be performed simultaneously.

3.2 Locally dependent distance and non-locally dependent distance

3.1(1),(2) To measure distance using these methods, one must bring an object to the location and observe its motion. In contrast, method (3) allows you to measure relative distance even from a great distance, as long as you know the apparent angle.

The meter standard, a reference object for length, and the speed of light used in the methods of 3.1(1) and (2) are fundamentally dependent on the properties of space and do not maintain absolute values. The speed of light is thought to change in a gravitational field and is also affected by the density of air, etc. Therefore, the measurement of distance using the methods of 3.1(1) and (2) generally changes depending on the conditions of the local location.

For example, it is thought that light travels more slowly in a strong gravitational field than in a weak gravitational field. If we accept this assumption, and radiate light upwards from the surface of a massive planet, and measure the distance from the planet's perspective using the speed of light as the reference, then by marking the points reached by the light at appropriate equal time intervals, we can create a coordinate system using these marks as a scale. Strictly speaking, if the speed of light cannot be considered constant, it is incorrect to use the method in 3.1(2), but if the distance traveled by light is very short, the speed of light can be considered constant. This local speed of light can be considered small in areas with high gravity and large in areas with low gravity. If we measure the distance using the speed of light as the reference in both cases, the distance will be shorter in areas with high gravity, but if we consider the speed of light to be absolute, then the distances between the two will be equal.

On the other hand, if we observe the markers at these coordinates from a location far from the planet, we will observe that the relative spacing between the markers is not equal. The closer we are to the planet's surface, the closer the markers are because gravity is stronger, and the further away we are from the planet, the wider the spacing becomes (Figure 3.1). However, this observation assumes that the light from the markers, viewed from a location far from the planet, is not bent along its path. In reality, if we were to attempt such a measurement, the light would be bent along its path, making accurate measurement difficult, although approximate measurement would be possible.

This indicates that the distance observed on a planet, relative to the speed of light, is not equal to the distance observed from a distant location. This is because the method of measuring distance differs in each case. Measurements on the planet used method 3.1(1) and (2), while measurements from distant locations used method 3.1(3). In other words, there are methods of measuring distance that depend on the local location and methods that do not directly depend on the local location.Methods 3.1(1) and (2) are local-dependent methods, while method 3.1(3) is a local-independent method. Let us call the distances measured by each method locally-dependent distance and non-local-dependent distance, respectively. This understanding is important, because if distance were limited to locally-dependent distance, then in a gravitational space, distance would differ from place to place, making comparisons of these distances extremely complex. However, by using non-local-dependent distance, distances observed in a gravitational space can be directly compared using the Euclidean concept of distance. Just as with time, there are non-local concepts for measuring distance.

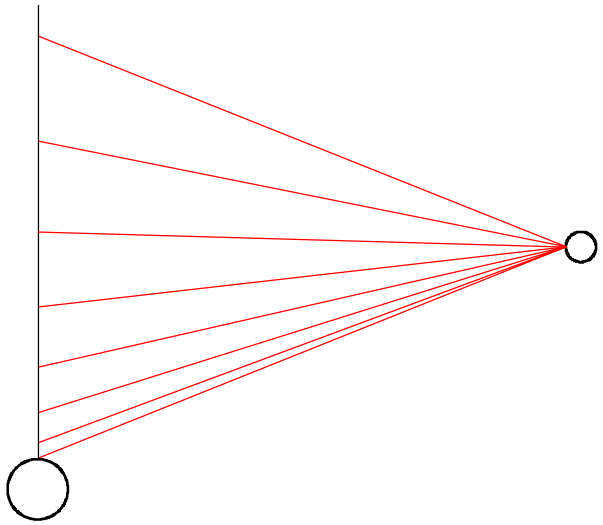


Figure 3.1 Locally dependent distance and non-locally dependent distance

3.3 Coordinates

Mathematically, coordinates are described as follows: "A set of numbers that represent the position of a point in space; each number is called a coordinate component. The method of assigning numerical values of coordinate components to each point in space is called a coordinate system." Various forms of coordinate systems have been devised, but the most common among them, Descartes' coordinate system, can be considered a hypothetical, mathematical, and conceptual requirement in which the x, y, and z axes are mutually orthogonal, extend to an infinite range, and by defining three points on each axis, it is possible to point to all points in space.

It is crucial to understand that a coordinate system is a hypothetical, conceptual construct, not a real one. Therefore, it is impossible to infer that the motion of a coordinate system implies physical limitations on its speed, changes in its scale, or a slowing of time. Since a coordinate system does not exist, it cannot influence the real natural world.

The next important point is that a coordinate system can encompass an infinite range of phenomena. As the example given in 3.2 illustrates, when introducing coordinate systems into physics, one cannot simply assume that their scope of application is infinite; attention must always be paid to their scope of application.