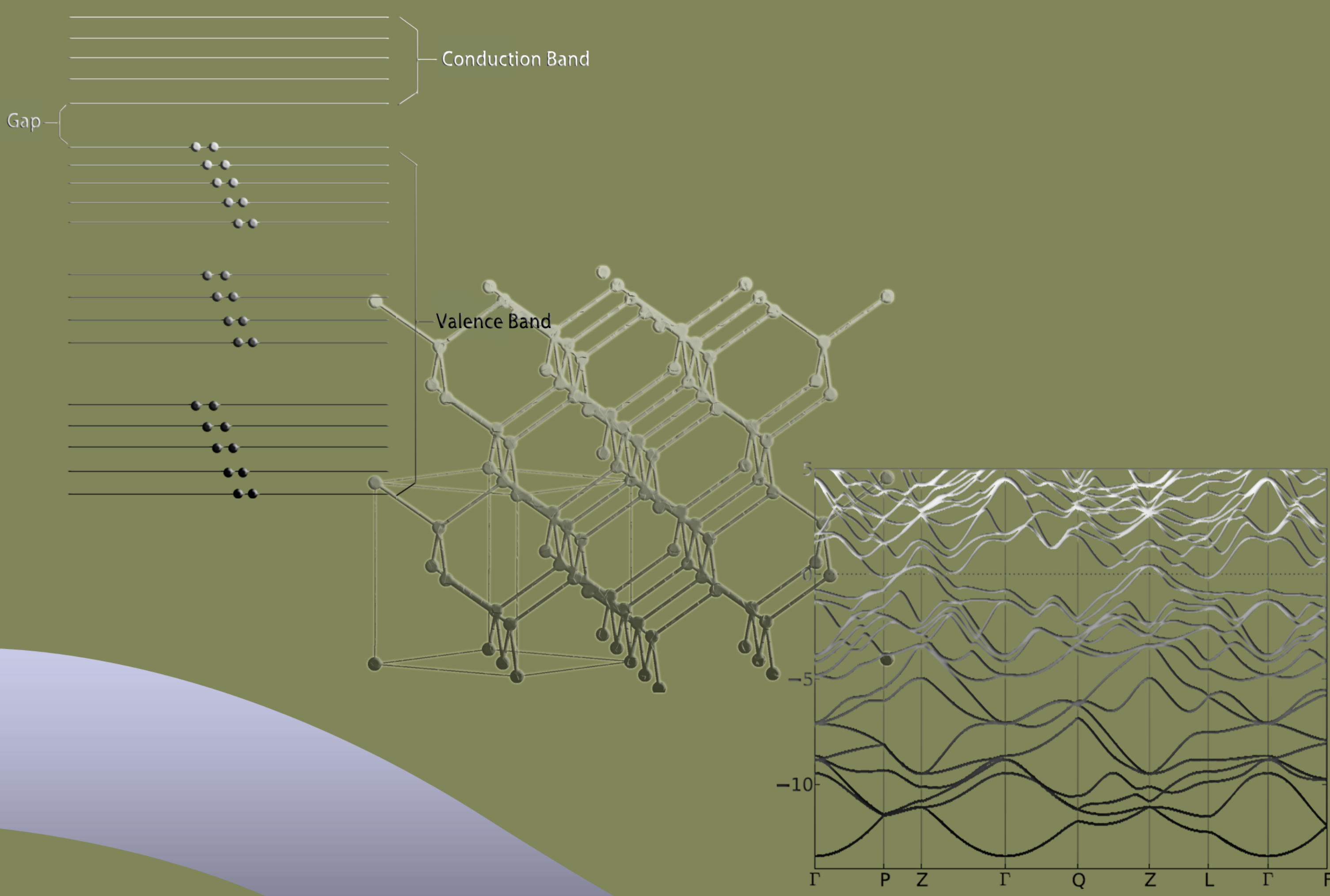
Queen Mary, University of London

School of Physics and Astronomy

General Understanding of Relativity



1. About Speed of Light

In common sense, if people are talking about the speed, they must specify the coordinate. For example, if we are walking on the train, it does not make sense to say our speed is 2m/s since people will never know whether this speed refers that relative to the train or the ground. If the train is moving relative to the ground, our speed to the ground obviously should consider the influence of moving train. The transformation of speed, or generally speaking, the transformation of space should follow the classical Galileo transformation. However, when physicists extend such basic rule, which we believe as a fact as man needs air to live, to the problem involving light, they finally failed. Here before going on, it should be pointed out the famous debate in the history about what light is. Particle or wave? Before 19th century, lots of physicists including Newton believed light is particle, then obviously medium is not necessary for spreading of light. In 19th century, Thomas Young successfully explained Newton rings using wave theory of light. Also Fresnel successfully explained diffraction of light based on wave theory. Together with the proposition of light as transversal but not longitudinal wave, the success of explaining series of experimental results using wave theory of light made people gradually accepted light as wave. However, new problem came that if light is wave, it should need some kind of medium to spread, if we imagine water wave. Historically, it was just the accepting of light as wave that led to aether theory rising up again. Now if we talk about the speed of light again within the framework of wave theory, also assuming the existence of aether (which is absolutely not moving), then what we mean by speed of light is relative to aether. However, the famous Michelson – Morley experiment destroyed the 'perfect' world, since it turns out that the speed of light will never change no matter in which coordinate (moving or not moving) we are talking about it!

After Michelson and Morley, series of experiments replicated corresponding result. Thus we have to believe the fact that speed of light will never change! The exact expression is given by Einstein as one of the basic assumptions for relativity theory: The speed of light in a vacuum is the same for all observers, regardless of their relative motion or of the motion of the light source. Imagine we are in space without gravity, if there is a 'train' moving in one direction with the speed of v_0, and someone on the train throws a ball in the opposite direction with the speed of v_0 (relative to the train) as well, the person standing on the ground will never get the ball since the speed of the ball is 0 relative to the ground. However for light, the thing is a bit different, even the light source is moving with the speed of light in one direction relative to the ground, we can still see the light standing on the ground without any moving!

2. About Twins Problem

Based on the discussion of part 1, we should naturally accept the non-existence of aether. Since speed of light is the same for any coordinate no matter it is moving or not, why should we bother imagining or trying to find the absolutely static coordinate aether? This is the basic understanding of theory of relativity, to say that everything in the world is relatively moving and nothing is absolutely static. Accepting the basic rule of theory of relativity, we then could have corresponding Lorentz transformation relationship of position, time, velocity, etc. between two different coordination. Detailed information refer to the online summary material for relativity. Here in this article, we only talk about the typical result that we can obtain based on Lorentz transformation rule. Basically, we can obtain two well known results: shrinking of length and extension of time. For the latter result, there exist a well known imaginary experiment - twins experiment. One of the twins travels on rocket with speed close to that of light, and the other stays on earth. Then after the brother on rocket traveling back from the universe, he should be younger than the other! How can that be possible? Well I should say this is people's misunderstanding of relativity theory. First of all, why people think the guy traveling on rocket should be younger than the other? That's because people only see the problem regarding the moving rocket as their static coordination (reference), then following Lorentz transformation relation people can easily draw the conclusion that time on the traveling rocket is shortest (which means the guy traveling on rocket is younger). However, do not forget the theory of relativity, which tells everyone has the right to say I am the static reference and anything else is moving relative to me! Thus in this case, if we look at the twins problem from the perspective of brother staying on earth, we could then find that things do turn around! In another word, in the first case, we are putting the clock on the traveling rocket and 'force' the guy staying on earth to use clock on the rocket to measure time. However in the second case, the guy staying on earth says, why should I use your clock? I use my own clock and you measure time using my clock!

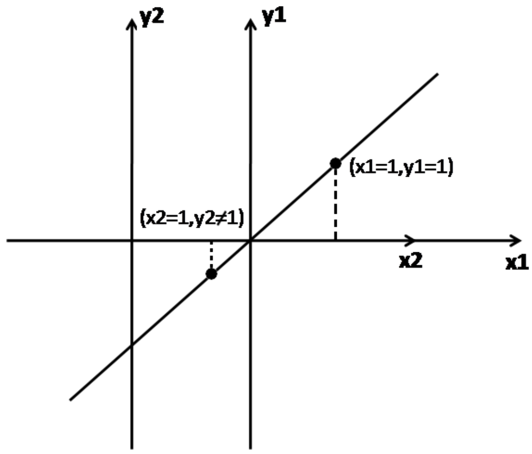


Figure. 1 2D coordinate analogue to 4D problem.

Then comes confusing question: who is wrong? Indeed, nobody is wrong! Because they are using different reference! More interestingly, there is no third party which can says 'Ok, I am the judge of the universe! My clock is correct!', because no one is absolutely static in the universe! (If aether exists, it should be the judge; however, it does not!) By now, we should understand that the originally thought independent 'TIME' does depend on the space where we measure the 'TIME'! Thus in relativity mechanics, time, together with 3D space forms a 4D coordinate. Then the twins problem can be easily explained in the time-space 4D coordinate. If we want to compare any of the four coordinates, including time, we have to locate ourselves in one specific 4D coordinate. Similarly, we can imagine the 2D analogue to 4D problem as shown in Figure 1. If two guys both look at the tilting line (assuming in coordinate 1, the function is $y = x$) from $x = 1$ in their own coordinate ($x_1 = 1$, $x_2 = 1$), the y value they see is obviously different ($y_1 = 1$, $y_2 \neq 1$). Then can we tell which one is wrong? Of course not! Because they are sitting in different coordinates! Now let's imagine the tilting line as the one-direction time line and extend the 2D coordinate to 4D. Similar to 2D case, even though two guys are sitting at the 'same' space point (let's say $x_1 = x_2 = 1$, $y_1 = y_2 = 1$, $z_1 = z_2 = 1$), they actually should see different time value (interval) if they are using different 4D coordinate!

3. Newton's First Law and Theory of Relativity

Let's at first put the exact expression for Newton's first law here:

> **Newton's First Law:** *When viewed in an inertial reference frame, an object either remains at rest or continues to move at a constant velocity, unless acted upon by an external force.*

However when we are talking about Newton's first law, usually we focus on 'rest', 'constant velocity' or 'external force' without noticing the prerequisite of 'inertial reference frame'. Or even we notice the necessity of 'inertial reference frame', we are always focusing on only one reference frame. It is usually the case that when we consider the force, motion or both of them of our object, we at first set up a specific reference frame and have a look at whether it is inertial or not. There is no problem with such kind of quite common idea. However if we think about Newton's first law from another point of view, we may find a new world! Let's say we have two reference frame both of which are inertial as stated in Newton's first law. Then what does Newton's first law tell us? For the first reference frame, if we do not have external force exerted on the object, we should have our object at rest or moving in a constant velocity. What about the second one? The same! Now if we call the two states 'at rest' and 'moving at constant velocity' compactly as 'uniform motion', we could then say observed in either of the two inertial reference frame we selected, our object will be always in the state of 'uniform motion' if there is no external force exerted on it. In another word, whether our object is in 'uniform motion' does NOT depend on which inertial reference frame we select.

There is no doubt what is discussed above stands when we have two inertial reference frames. What about three? And four? Indeed, according to theory of relativity, every inertial reference frame should be definitely equivalent, which is to say we could have as many inertial reference frames as we can imagine! And actually we should say Newton's first law stands for all inertial reference frames!

If the object in interest is in the state of 'uniform motion' in one inertial reference frame, then it will be definitely in the state of 'uniform motion' in any other inertial reference frames! This is just what the principle of relativity is, to say any law of physics should stay in the same form regardless of the inertial reference frame we select!