Chapter 12, Did God Have Any Choice?

Learning Notes, Physics for Poets

1 The Principle of Equivalence

To develop his theory of gravity, which he called general relativity, Einstein added one more postulate to the theory of relativity, mainly:

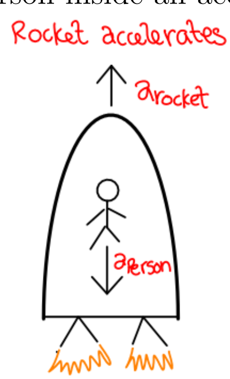
No experiment performed in one place cna distinguish a gravitational field from an accelerated reference frame.

The words in "one place" are important. Einstein did not eliminate all distinctions between gravity and accelerated reference frames. If we compare the fall of objects in different places on Earth, we will find that they all head toward the Earth's center. No accelerated reference frame can duplicate that pattern.

What Einstein is saying is simply that all objects respond to a gravitational field in the same way they respond to being in an accelerated frame.

We can see this more graphically through the following examples:

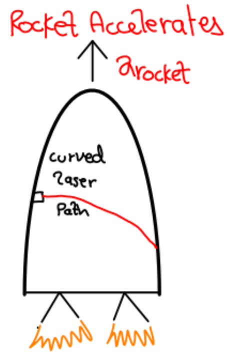
Figure 1: A person inside an accelerating rocket



As the rocket accelerates the person feels as if he is pulled down to floor (the floor is pushing against his feet); to him it feels just as if he is subject to the force of gravity.

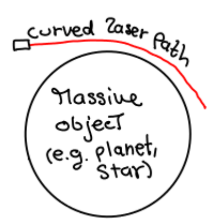
But this equivalence effect also works on light (as it should since we know energy is equivalent to mass). The following example shows how the path of light is curved in an accelerated frame.

Figure 2: A laser inside an accelerating rocket



As you can see the laser beam curves down (the rocket moves up while the light is travelling) and the same effect will happen in a gravitational field.

Figure 3: Light affected by a gravitational field



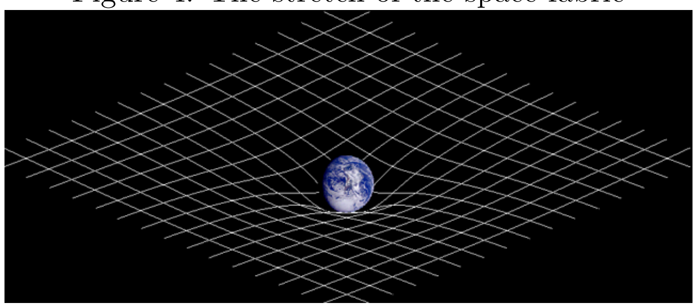
Einstein's conlusion was that there is absolutely no need for a "force" of gravity as long as space and time are curved.

However, it is hard to imagine what curved space-time actually means, it's almost like trying to figure out whether the earth is round by looking at a map. But, let's go over a couple of examples and see if our imagination can help us visualize these concepts.

What is Curved Space?

To visualize curved space it is helpful to think of the planets in our solar system as if they are all sitting on a thin flat fabric, and because the planets have mass, they strech down the fabric. The following illustration helps convey the immage.

Figure 4: The stretch of the space fabric

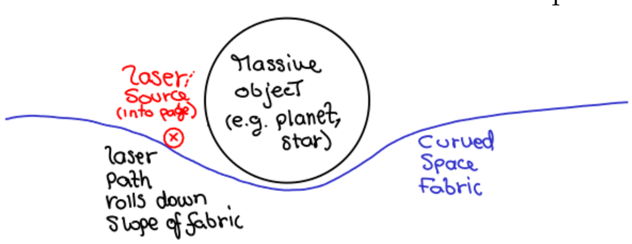


But how does a curved space account for the effect of gravity? It does so by affecting the path of objects as they coast along on top of the fabric, the results is a type of motion akin to objects subject to the force of gravity.

So, instead of talking about a force of attraction, we can say that the object "rolled down the curved space fabric". But, we can also see that the fabric stretches more as we place more massive objects on it, this is akin to the mass force relationship of gravity.

Let's take another example: We previously saw the accelerating rocket and the curved path of light. But, we can also see a similar effect if we look at the path of light (x goint into the page) as it rolls down in a curved space fabric.

Figure 5: The Laser rolls down the curved space fabric

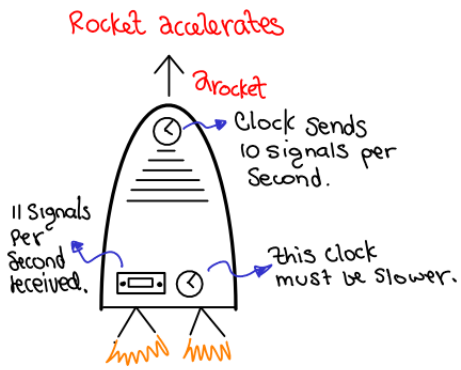


What is Curved Time?

Curved time is concept which can be a little bit more abstract, mainly because we are used to taking time as a constant (e.g. an hour is an hour anywhere) but it simply means that time is also affected by the geometry of the space fabric.

the following example helps convey this concept:

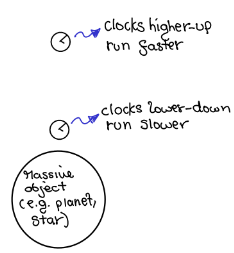
Figure 6: Clocks in an accelerated frame



The rocket is accelerating, so while the top clock is putting out signals at a constant rate (10 signals per second), the bottom of the rocket is moving faster, and the detector is receiving more signals per second (11 signals per second). Thus, the bottom clock must be running slower, and the same effect must(and does) happen in a gravitational field.

So, general relativity tells us that clocks closer to a massive object (stronger gravitational field) run slower and those farther away run faster (weaker gravitational field). Here is a visual picture.

Figure 7: Clocks in a gravitational field

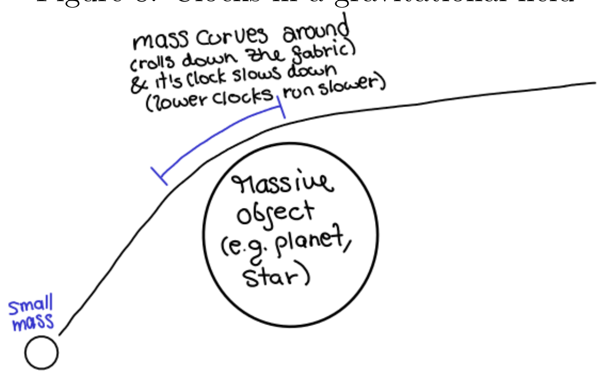


Curved space-time the complete picture

Our complete picture now involves a reality where mass curves the fabric of space and time. This effect not only accounts for the mechanics and interactions of large objects which we previously accounted for through the use of gravity, but it introduces a new concept, time is no longer a constant.

I leave you with the following picture.

Figure 8: Clocks in a gravitational field



As the mass passes close to the large planet it rolls down the stretched space fabric and curves around the planet, it's clock also slows down.