Chapter 7

The General Theory of Relativity

The General Theory of Relativity is, as the name indicates, a generalization of the Special Theory of Relativity. It is certainly one of the most remarkable achievements of science to date, it was developed by Einstein with little or no experimental motivation but driven instead by philosophical questions: Why are inertial frames of reference so special? Why is it we do not feel gravity's pull when we are freely falling? Why should absolute velocities be forbidden but absolute accelerations by accepted?

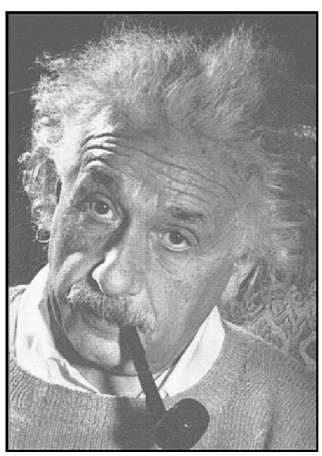

Figure 7.1: Einstein

7.1 The happiest thought of my life.

In 1907, only two years after the publication of his Special Theory of Relativity, Einstein wrote a paper attempting to modify Newton's theory of gravitation to fit special relativity. Was this modification necessary? Most emphatically yes! The reason lies at the heart of the Special Theory of Relativity: Newton's expression for the gravitational force between two objects depends on the masses and on the distance separating the bodies, but makes no mention of time at all. In this view of the world if one mass is moved, the other perceives the change (as a decrease or increase of the gravitational force) *instantaneously*. If exactly true this would be a physical effect which travels faster than light (in fact, at infinite speed), and would be inconsistent with the Special Theory of Relativity (see Sect. 6.2.7). The only way out of this problem is by concluding that Newton's gravitational equations are not strictly correct. As in previous occasions this does not imply that they are "wrong", it only means that they are not accurate under certain circumstances: situations where large velocities (and, as we will see, large masses) are involved cannot be described accurately by these equations.

In 1920 Einstein commented that a thought came into his mind when writing the above-mentioned paper he called it "the happiest thought of my life":

> *The gravitational field has only a relative existence...* Because for an observer freely falling from the roof of a house – *at least in his immediate surroundings* – there exists no gravitational field.

Let's imagine the unfortunate Wile E. Coyote falling from an immense height [1]. As he starts falling he lets go of the bomb he was about to drop on the Road Runner way below. The bomb does not gain on Wile nor does it lag behind. If he were to push the bomb away he would see it move with constant speed in a fixed direction. This realization is important because this is exactly what an astronaut would experience in outer space, far away from all bodies (we have good evidence for this: the Apollo 10–13 spacecrafts did travel far from Earth into regions where the gravitational forces are quite weak).

Mr. Coyote is fated to repeat the experience with many other things: rocks, magnets, harpoons, anvils, etc. In all cases the same results are obtained: with respect to him all objects, irrespective of composition, mass,

[1] I ignore air resistance