What is the “Equivalence Principle” and Why is it a Big Deal?

Robert M. Wald

The Equivalence Princlple

The *equivalence principle* is the statement that all bodies fall the same way in a gravitational field.

This fact was well known to Galileo and he (supposedly) demonstrated it by dropping two very different objects off of the leaning tower of Pisa. So, why is this a big deal, and why did Einstein make such a fuss about it?

Inertial Motion

A cornerstone of physics since the time of Galileo and Newton is that a body that is subject to no external forces moves with "uniform velocity." This statement is actually somewhat circular, because one has to say who is measuring the velocities. A better formulation of this statement is that the possible motions of bodies subject to no external forces comprise a particular class of motions, called *inertial*. Any pair of inertial bodies move at uniform velocity with respect to each other.

A key property of the inertial motion of a body is that it is independent of the nature/composition of the body.

Einstein's "Happiest Thought"

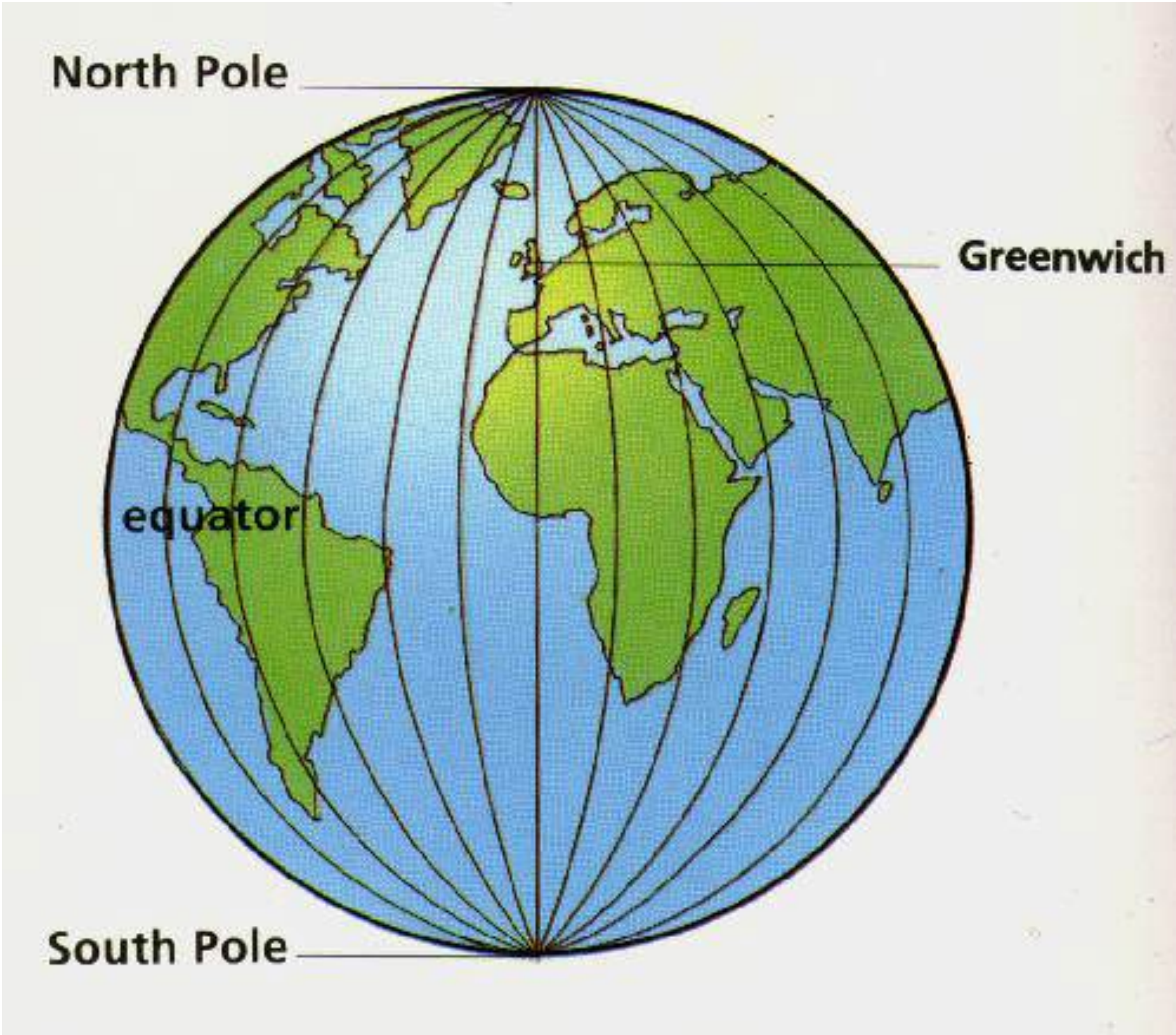
The key insight that guided Einstein to formulate general relativity was that freely falling bodies in a gravitational field should be thought of as being in inertial motion! This idea is consistent precisely because of the equivalence principle. However, for this idea to work, one must give up many properties normally assumed for inertial motions. For example, two freely falling bodies near the surface of the Earth do not move at uniform velocity with respect to each other; in particular, even if they start at rest with respect to each other, they pick up a nonzero relative velocity because they both fall towards the center of the Earth.

Einstein had this insight (which he referred to as his "happiest thought") in 1907. Within a few years, he had the key concepts that could implement this idea. However, he went astray for a few years in seeking the equations that would govern his new theory of "general relativity." Then, in a remarkable series of papers in late 1915, he formulated general relativity as we know it today.

A Key Concept: Geodesics

In ordinary geometry, a *geodesic* is a curve that is "as straight as possible;" equivalently, it is a curve that minimizes the distance between pairs of points. In Euclidean geometry, geodesics are straight lines; in spherical geometry, geodesics are great circles. In spherical geometry, initially parallel geodesics do not remain parallel.

Einstein formulated special relativity in 1905. By 1908, it was realized that the structure of space and time in special relativity could be described by a *spacetime metric*. Geodesics of this spacetime metric of special relativity correspond to inertial motions.


North Pole
Greenwich
equator
South Pole

The different properties of freely falling bodies near the Earth—as compared with inertial motions in special relativity—can be accounted for by having a curved spacetime geometry near the Earth!

General Relativity

So, Einstein's path to general relativity was as follows:

equivalence principle $\rightarrow$ freely falling motion in a gravitational field $\equiv$ inertial motion $\rightarrow$ gravity is not a "force" but is curved spacetime geometry $\rightarrow$ spacetime geometry is not "inert background structure" but is dynamical $\rightarrow$ the spacetime metric satisfies Einstein's equation, relating its curvature to the properties of matter.

Thus, the equivalence principle lies at the root of general relativity. It really is a big deal!