The Equivalence Principle (This is written by Dr. Sabine Hossenfelder)

Some time in sixth grade a well-meaning librarian shoved me out of the Scifi/Horror aisle and into the dreaded youthbook (Jugendbuch) section, an act that had unintended consequences. The books in that aisle were neatly marked with dots, the more dots the higher the recommended age. I didn't immediately realize that blue dots were meant for boys and red ones for girls, so ended up with a book that recommended to handle unwanted occurrences of sexual arousal by mentally focusing on something decidedly unsexy, such as potatoes or General Relativity.

This advice changed my view of the world. Not only did I realize that being a teenager with a Y-chromosome can't be easy either, it also explained why my male classmates were suddenly developing interests in things like Special Relativity or Scanning Tunnel Microscopes (Nobel Prize '86). It made also sense they were usually very irritated if a girl attempted to join them: all that was just suppressed hormones, the poor guys*. It further revealed a deep connection between General Relativity and potatoes that hadn't previously occurred to me. Most disturbingly however, it labeled General Relativity as unsexy, a fact that has bothered me ever since.

Over the course of years I moreover had to notice that General Relativity is a subject of great mystery to many, it's a word that has entered the colloquial language as the incomprehensible and un-understandably complicated result of a genius' brain. My physics teacher notably told me when getting tired of my questions that there are maybe three people in the world who understand General Relativity, thereby repeating (as I found out later) a rumor that was more than half a century old (see Wikipedia on the History of General Relativity).

[*Unrelated material edited out.*]

That leads me now directly to the Equivalence Principle, the cornerstone of General Relativity. Googling 'Equivalence Principle' it is somehow depressing. Wikipedia isn't wrong, but too specific (the Equivalence Principle doesn't have anything to do with standing on the surface of the Earth). The second hit is a NASA website which I find mostly confusing (saying all objects react equally to gravity doesn't tell you anything about the relation of gravitational to inertial mass). The third[1] and fourth[2] hits get it right, the fifth is wrong (the locality is a crucial ingredient).

So here it is:

- **The Equivalence Principle:** Locally, the effects of gravitation (motion in a curved space) are the same as that of an accelerated observer in flat space.

That is what Einstein explains in his thought experiment with the elevator. If you are standing in the elevator (that is just a local patch, theoretically infinitesimally small) you can't tell whether you are pulled down because there is a planet underneath your feet, or because there is a flying pig pulling up the elevator. This website has two very nice mini-movies depicting the situation.[3]

If you could make your elevator larger you could however eventually distinguish between flat and curved space because you could measure geodesic deviation, i.e. the curvature.

If you think of particles, the Equivalence Principle means that the inertial mass is equal to the gravitational mass, which has been measured with impressive precision. But the above formulation makes the mathematical consequences much clearer. To formulate your theory, you will have to introduce a tangential bundle on your curved manifold where you can deal with the 'local' quantities, and you will have to figure out how the cuts in this bundle (tensors[4]) will transform under change of coordinates. If you want your theory to be independent of that

choice of coordinates it will have to be formulated in tensor equations. Next thing to ask is then how to transport tensors from one point to the other, which leads you to a 'covariant' derivative[5].

The Equivalence Principle is thus a very central ingredient of General Relativity and despite its simplicity the base of a large mathematical apparatus, it's the kind of insight every theoretical physicist dreams of. It gives you a notion of a 'straightest line' in curved space (a geodesic) on which a test particle moves. This curve most notably is independent of the mass of that particle: heavy and light things fall alike even in General Relativity (well, we already knew this to be the case in the Newtonian limit). For a very nice demonstration see the video on the NASA website[6] (*the Apollo 15 astronaut dropping the hammer and the feather on the Moon*). Please note that this holds for point-like test particles only, it is no longer true for extended or spinning objects, or for objects that significantly disturb the background.

The Equivalence Principle however is not sufficient to give you Einstein's field equations that describe how space is curved by its matter content. But that's a different story. It remains to be said all this is standard textbook knowledge and General Relativity is today not usually considered a large mystery. There are definitely more than 3 people who understand it. We have moved on quite a bit since 1905.

Bottomline

General Relativity is sexy.

Though I doubt there's more than three people in the world who really understand potatoes.

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Footnotes:

* In the more advanced stages of confusion they start referring to physical theories as women.

[1] http://csep10.phys.utk.edu/astr162/lect/cosmology/equivalence.html [Retrieved 01/25/12]

[2] http://www.phy.syr.edu/courses/modules/LIGHTCONE/equivalence.html [Retrieved 01/25/12]

[3] *ibid.*

[4] *Tensors* are geometric objects that describe linear relations between vectors, scalars, and other *tensors*.

[5] In physics, a **covariant transformation** is a rule (specified below), that describes how certain physical entities change under a change of coordinate system.

[6] http://nssdc.gsfc.nasa.gov/planetary/lunar/apollo_15_feather_drop.html [Retrieved 01/25/12]