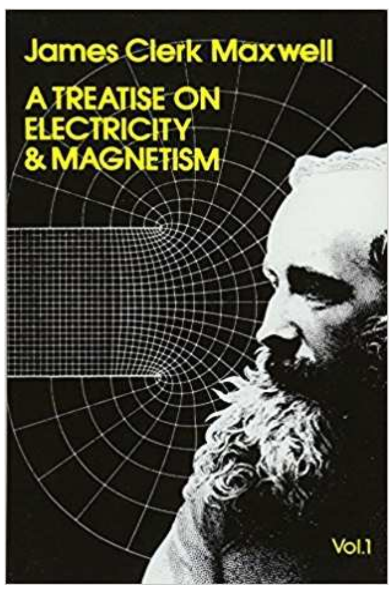
1.4. General Relativity

Note. James Clerk Maxwell (1831–1879) published his theory of electromagnetism in 1865 in "A Dynamical Theory of the Electromagnetic Field," *Philosophical Transactions of the Royal Society of London*, **155** 459–512 (1865). A copy of the original paper is online at: `http://rstl.royalsocietypublishing.org/content/155/459`. He spelled out the results in greater detail in his two volume *A Treatise on Electricity and Magnetism*, Oxford: Clarendon Press (1873). These books are online at

`https://archive.org/details/electricandmagne01maxwrich` and

`https://archive.org/details/electricandmag02maxwrich`

This work is stil in print by Dover Publications (it is about $20 per volume):



The theory predicted that all electromagnetic waves travel at the speed of light. This was incompatible with classical mechanics unless preferred inertial frames of reference were introduced, leading to the discovery of special relativity.

Note. Einstein was motivated to develop a new theory of spacetime and gravity by two ideas.

(1) The Principle of Equivalence.

Newton's Second Law of Motion ($\vec{F} = m\vec{a}$) treats "mass" as an objects resistance to changes in movement (or *acceleration*). This is an objects *inertial mass*. In Newton's Law of Universal Gravitation ($F = GMm/r^2$), an objects mass measures its response to *gravitational attraction* (called its *gravitational mass*). Einstein was bothered by the dichotomy in the idea of mass:

inertial mass	gravitational mass
acceleration	gravitational acceleration

As we'll see, he resolved this by putting gravity and acceleration on an equivalent footing. This is discussed in Chapters 19 and 20 of Einstein's *Relativity: The Special and General Theory* (translated by Robert W. Lawson), NY: Three Rivers Press (1961). What Newton thought of as a gravitational field, Einstein dealt with as a curvature of spacetime (as opposed to the flat spacetime of special relativity).

(2) Mach's Principle.

"[Ernst] Mach [1838–1916] felt that all matter in the universe should contribute to the local definition of 'nonaccelerating' and 'nonrotating'; that in a universe devoid of matter there should be no meaning to these concepts. Einstein accepted this idea and was strongly motivated to seek a theory where, unlike special relativity, the structure of spacetime is influenced by the presence of matter." (This quote is from page 9 of Wald.)

Note. In the next two chapters we "give a precise, mathematical expression of the ideas discussed in this chapter" (page 9 of Wald). In Chapter 2 we introduce manifolds, vectors, and tensors. In Chapter 3 we discuss parallel transport, curvature, and geodesics. Chapter 4 is on relativity, Chapter 5 covers cosmology, and Chapter 6 addresses the Schwarzschild solution to the field equations which is used in the exploration of black holes.

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