Minkowski's program of geometrizing physics and general relativity

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Gravitation as a separate agency becomes unnecessary
Arthur S. Eddington [1]

An electromagnetic field is a "thing;" gravitational field is not, Einstein's theory having shown that it is nothing more than the manifestation of the metric
Arthur S. Eddington [2]

In his revolutionary 1908 lecture *Space and Time* Minkowski initiated the first program of geometrizing physics and stated that the laws of physics can find their most complete expressions in terms of the geometry of spacetime (regarded by him as the *true* reality) and reported the first instances of the implementation of his program – by regarding the discovered by him four-dimensional physics as spacetime geometry (or in Minkowski's terminology "world-geometry" [3]) he *explained*

- *why* inertial observers in relative motion have different times (that was merely *postulated* by Einstein) and different spaces (first realized by Minkowski), which is *impossible in a three-dimensional world* (it is this explanation that made Minkowski realize that the *true* reality is a four-dimensional world – *die Welt* or spacetime);
- the absolute distinction between inertial (non-resistant) and accelerated (resistant) motion since they are represented by *distinct* timelike worldlines (or rather worldtubes) – straight and curved (deformed), respectively; this *geometrical* distinction immediately leads to an attractive explanation of the corresponding *physical* distinction between inertial and accelerated motion (because Minkowski regarded the particles' worldtubes as *real*) – inertial motion cannot be detected experimentally, whereas accelerated motion can be (because an accelerated particle is a *deformed* worldtube in spacetime, which *resists* its static deformation);
- the equivalence of all inertial observers (or inertial frames), that was also *postulated* by Einstein – they are equivalent because they are all *straight* worldtubes; this explanation also explains the physical meaning of the relativity principle – physical laws are the same for all inertial observers because each observer describes the physical phenomena exactly in the *same* way – in his own space, in which he is at rest, and by using his own time;
- the *postulated* by Einstein constancy of the speed of light: it is the same for all observers, because each of them measures it exactly in the *same* way – in his own space, in which he is at rest, and by using his own time;
- the physical meaning of length contraction – the relativistic length contraction of a rod, for example, is possible *if and only if* the rod's worldtube is a real four-dimensional object, because only then two inertial observers' spaces (which form an angle corresponding to the observers' relative velocity) can intersect the rod's worldtube at two cross-sections (measured as *two* three-dimensional rods) of *different* length.

However, most physicists seem to believe that it was Einstein's general relativity which first geometrized physical phenomena. This is an unfortunate historical injustice on two counts:

- many relativists are probably not fully aware that it was Minkowski who first introduced the program to geometrize *all* physics (not just gravitation) – to regard the four-dimentional physics as spacetime geometry – and who started to employ this program to the physics of flat spacetime;
- contrary to common belief, Einstein himself did not believe that general relativity geometrized gravitation: "I do not agree with the idea that the general theory of relativity is geometrizing Physics or the gravitational field" [4]. Einstein looked at the mathematical formalism of general relativity as pure mathematics and regarded gravitation as a physical interaction involving exchange of gravitational energy and momentum.

Despite that according to the currently accepted understanding of general relativity, which was initiated and greatly influenced by Einstein himself, gravitation is a physical interaction involving exchange of gravitational energy and momentum, I will examine, following Eddington [2], whether taken at face value general relativity geometrizes gravitation *fully*, and whether indeed "gravitation as a separate agency becomes unnecessary." I will do this by noting that Minkowski, had he lived longer, would have certainly seen general relativity as a triumph of his program of geometrizing physics and would have very likely demonstrated that the only rigorous interpretation of the mathematical formalism of general relativity is that gravitation is *nothing more* than manifestation of the non-Euclidean geometry of spacetime in full agreement with his program. Indeed, as a mathematician (who would not allow anything external, like gravitational energy and momentum, to be smuggled into the theory) Minkowski might have concluded that all gravitational phenomena are completely explained in general relativity as manifestations of the non-Euclidean geometry of spacetime without the need to assume that gravitational interaction is causing the gravitational phenomena:[1]

- a particle, whose worldline is geodesic, is a free particle moving by inertia (the geodesic principle); therefore the motion of bodies falling toward the Earth's surface and of planets orbiting the Sun (whose worldtubes are geodesic) is inertial, i.e., interaction-free, because the very essence of inertial motion is motion which does not involve any interaction (and any exchange of energy and momentum) whatsoever.

- the *deformed* worldtube of a particle on the Earth's surface may be regarded as giving rise to an inertial force (a static restoring force in the particle's *deformed* worldtube), which has been traditionally called gravitational force or the particle's weight.

- what is called gravitational energy appears to be inertial energy arising from the work done by inertial forces with which free particles (moving by inertia), represented by geodesic worldtubes, resist any deformation of their worldtubes (i.e., resist when prevented from moving by inertia); for this reason gravitational waves could not carry gravitational energy as Eddington stressed it in his fundamental treatise on the mathematical and physical foundations of general relativity *The Mathematical Theory of Relativity*.[2] A closer look [6] at Feynman's famous sticky bead argument [7] (regarded by many as demonstrating that gravitational waves do carry gravitational energy) reveals that kinetic, not gravitational, energy is converted into heat; more precisely inertial not kinetic energy is converted into heat because the bead is initially at rest and does not possess kinetic energy (a simple calculation [8] shows that kinetic and inertial energy are the same thing, but the adequate term, as the sticky bead argument demonstrated, is inertial energy since it reveals the very origin of this energy – the work done by inertial forces when particles are prevented from moving by inertia).

References

[1] A.S. Eddington, The Relativity of Time, *Nature* **106**, 802-804 (17 February 1921); reprinted in: A. S. Eddington, *The Theory of Relativity and its Influence on Scientific Thought: Selected Works on the Implications of Relativity* (Minkowski Institute Press, Montreal 2015) pp. 27-30, p. 30

[2] A.S. Eddington, *The Mathematical Theory of Relativity* (Minkowski Institute Press, Montreal 2016) p. 233.

[3] A. Sommerfeld, To Albert Einstein's Seventieth Birthday. In: *Albert Einstein: Philosopher-Scientist*. P. A. Schilpp, ed., 3rd ed. (Open Court, Illinois 1969) pp. 99-105, p. 102

[4] A letter from Einstein to Lincoln Barnett from June 19, 1948; quoted in [5].

[5] D. Lehmkuhl, Why Einstein did not believe that General Relativity geometrizes gravity. *Studies in History and Philosophy of Physics*, Volume 46, May 2014, pp. 316-326.

[6] V. Petkov, Physics as Spacetime Geometry. In: A. Ashtekar, V. Petkov (eds), *Springer Handbook of Spacetime* (Springer, Heidelberg 2014), pp. 141-163

[7] Sticky bead argument, `https://en.wikipedia.org/wiki/Sticky_bead_argument`

[8] V. Petkov, On Inertial Forces, Inertial Energy and the Origin of Inertia, published as Appendix B in V. Petkov, *Inertia and Gravitation: From Aristotles Natural Motion to Geodesic Worldlines in Curved Spacetime* (Minkowski Institute Press, Montreal 2012).

[1] The failures so far to create a theory of quantum gravity may have a simple but unexpected explanation – it might turn out that gravitation is not a physical interaction and therefore there is nothing to quantize.

[2] "The gravitational waves constitute a genuine disturbance of space-time, but their energy, represented by the pseudo-tensor t_{μ}^{ν}, is regarded as an analytical fiction" [2, p. 260] (it cannot be regarded as an energy of any kind for the well-known reason that "It is not a tensor-density and it can be made to vanish at any point by suitably choosing the coordinates; we do not associate it with any absolute feature of world-structure," *ibid*, p. 136).