Does general relativity explain inertia?

As far as I understand it general relativity does not explain the origin of the inertial mass m_i in Newton's law of motion $\vec{F} = m_i\ d\vec{v}/dt$ but rather it simply applies the concept to curved spacetime.

For example if we have a particle with inertial mass m_i and charge q moving in flat spacetime in an electromagnetic field $\vec{E}, \vec{B}$ with relativistic 3-velocity $\vec{v}$ then its equation of motion with respect to its proper time τ is

$$q(\vec{E} + \vec{v} \times \vec{B}) = m_i \frac{d\vec{v}}{d\tau}. \tag{1}$$

In curved spacetime the equation of motion (1) becomes

$$q\ F^\mu{}_\nu\ v^\nu = m_i \left(\frac{dv^\mu}{d\tau} + \Gamma^\mu_{\rho\sigma}\ v^\rho\ v^\sigma \right) \tag{2}$$

where $F^\mu{}_\nu$ is the electromagnetic tensor, v^μ is the 4-velocity of the particle and $\Gamma^\mu_{\rho\sigma}$ is the metric connection.

Neither Eqn (1) nor Eqn (2) actually explain *why* it takes a force $\vec{F} = m_i\ \vec{a}$ in order to impart an acceleration $\vec{a}$ to an object with an inertial mass m_i.

Is this correct?

general-relativity classical-mechanics mass inertia

edited Aug 1 '20 at 9:38

asked Jul 31 '20 at 15:51

John Eastmond

4,585 1 15 30

4 Answers

Indeed, the properties of inertia must be assumed as they are in order to formulate general relativity at all.

It could be, for example, that the attempts at formulating a form of emergent gravity will also lead to formulation of a theory of emergent inertia.

It could be, I don't know, that some physicists regard inertia as a phenomenon that is irreducible. With such an expectation you would have that even if a Grand Unified Theory is developed, inertia would still be out of scope for such a theory.

As you point out, the electromagnetic interaction causes change of velocity with respect to the local inertial coordinate system. As we know, general relativity subsumes special relativity (just as special relativity subsumed Newtonian dynamics). General relativity inherits from special relativity: interactions such as the electromagnetic interaction cause change of velocity with respect to the local inertial coordinate sytem.

The nature of progress in science is that there is always a 'choose your battles' judgement call. The best known example: when Newton proposed the law of Universal Gravity he could not explain that law. In order to make progress the inverse square of gravity had to be assumed as is. Those who did try explanation (Lesage's shadow) were only bogging themselves down.

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edited Mar 5 at 9:44
Frederic Thomas
5,073 3 18 35

answered Jul 31 '20 at 16:56
Cleonis
13k 1 17 43

Cleonis' remark that some physicists may "regard inertia as a phenomenon that is irreducible" is consistent with descriptions of spatial expansion as continuing at a "quasi-inertial" or "asymptotically inertial" rate, which I've noticed in some cosmological papers, re post-Big Bang phenomena. – Edouard Aug 1 '20 at 2:02

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The Einstein equations imply that a suitably localized blob of energy-momentum that is not interacting with other field will follow (ignoring finite size effects) a geodesic with mass m, where m is the mass monopole moment of the blob. In this sense, the connection between inertia and the gravitational mass is made.

Any interactions will cause the blob to deviate from the geodesic with some 4-acceleration. Multiplying this acceleration with the mass m *defines* the force with which the interaction acts on the blob. (I.e. "force" is not a fundamental concept, but a rather a useful bookkeeping quantity.)

The derivation of these facts turns out to be very subtle, and has only been really understood in the last two decades through the work of (among others) Poisson, Pound, Weatherall, Harte, and Geroch.

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answered Jul 31 '20 at 16:20
mmeent
7,638 1 12 24

What you are writing about is the case of motion of an entity that is *not interacting with any other field*. However, the subject of the question is the very case where a particle with inertial mass is interacting with another field (with the omnipresent electromagnetic field as obvious example). – Cleonis Jul 31 '20 at 17:04

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The gravitational mass of a piece of matter [or more generally the (stress)-energy-(momentum) tensor, but let's stick to mass] is what causes the curvature of spacetime, i.e. the gravitational field, which makes all non-interacting masses move on a geodesic curve. An object falling free in such a spacetime doesn't "resist" to the free fall. Which is the reason gravity is by some not considered a real force (an object not resisting acceleration caused by, say, the electric force would reach the speed of light in an instant).
An free falling object would still follow a geodesic in a curved spacetime if inertial mass didn't exist or if the inertial mass and gravitational mass weren't the same. Gravitational mass and inertial mass are *assumed* to be the same (equivalent) in GR (this is one of the cornerstones of GR).
This doesn't *explain* inertial mass, but if inertial mass didn't exist (contrary to gravitational mass) or wasn't the same as gravitational mass, the universe would look very different.
If the inertial mass was half the gravitational mass, the acceleration in the elevator Gedankenexperiment would have to be twice the one experienced in an equivalent (local) gravitational field, like the upward acceleration we would feel pushing us upward while standing on earth. Or imagine what happens in the Universe if inertial mass would be zero.
I guess Einstein realized the two forms of mass *had* to be equal because if this was *not* the case the Universe would look very different. The fact that the Universe "is as it is" *implies* that there is a gravitational mass and an equivalent inertial mass, it doesn't *explain* the origin of inertial mass (the resistance to being accelerated by one of the three basis forces) but only its consequences.
And like you wrote, it's assumed that the Higgs mechanism explains gravitational mass (which I doubt though), but, even though they are equivalent, the mechanism doesn't explain inertial mass. So the short answer is "no".

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answered Aug 2 '20 at 21:35
Deschele Schilder
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Correct. Inertial mass is a separate concept than gravitational mass/charge, and does not have to equal it, just as in electromagnetism the electric charge of an item does not equal the inertial mass. Einstein's theory takes as a postulate* that the gravitational 'charge' of an object is equal to the inertial mass and of the same units; this is called the Weak Equivalence Principle.

For further explanation, I direct you to the second chapter of Carrol's book, *Spacetime and Geometry*.

*Well, the theory properly postulates both the above and the Einstein Equivalence Principle

Well, the theory properly postulates both the above and the Einstein Equivalence Principle, which is that in the limit, not only is the motion of a particle in a gravitational field indistinguishable from its motion in an accelerating frame (which is what the Weak Equivalence

Principle is logically equivalent too; think about it!), it is impossible to tell if it either. However, the generalization

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answered Aug 2 '20 at 21:51

John Dumancic

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