Re: Does gravity do work on the freely falling body?

Source: http://sci.tech−archive.net/Archive/sci.physics.relativity/2009−04/msg01154.html

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- *From*: Tom Roberts <tjroberts137@xxxxxxxxxxxxx>
- *Date*: Fri, 24 Apr 2009 00:29:18 −0500

Phil wrote:

> On Apr 22, 7:51 pm, Tom Roberts <tjroberts...@xxxxxxxxxxxxx> wrote:
>
>> In coordinates fixed to my office, a falling object has nonzero acceleration. Note that this statement is explicitly coordinate dependent. When I consider the 4−acceleration of the object, it is zero (neglecting air resistance and other minuscule effects). The un−qualified word "acceleration" could refer to either of these, and the resulting confusion is the basis of your question.
>
> Tom, I appreciate your response. I am not sure where you are confused regarding the relationship of coordinate acceleration.

I am not confused. But when you use the word "acceleration" without qualification (or explaining what you mean by it), then you invite your reader AND YOURSELF to be confused. I just gave an example where one meaning of "acceleration" is zero and a different meaning of "acceleration" is nonzero −− such PUNs generally destroy an argument.

And generate heated and endless debates around here.

> In regard to
> gravity, it is also a reasonable question to ask, how does gravity effect the motion of objects. We seemingly have two choices. Either gravity is a force impressed from the surface −−− OR −−− gravity is the acceleration of inertial frames.

Well, that is related to the difference in the two basic MODELS of gravity we have: in Newtonian gravitation it is a force, and in GR it isn't a force, it is a manifestation of the geometry of spacetime. As the latter has proven to be significantly more accurate in agreement with experiments, NG has been relegated to being a mere approximation to GR. This is the way virtually all physicists consider this, today (among those who have considered the question; some have not).

There are other models, such as Brans−Dicke theory, and several others. At present they have not been experimentally distinguished from GR.

> I am suggesting, that if one takes in sufficient evidence it is possible to determine whether it is the inertial frames which are accelerated OR the surface frame.

First one has to specify what you mean by "accelerated". You seem to have some notion that "acceleration" is an intrinsic property of a frame; that can apply ONLY if one interprets your statement as referring to 4−acceleration. But "4−acceleration of a frame" is tricky; the 4−acceleration of a test particle is well defined, and the best I can come up with for "the" 4−acceleration of a frame is to consider the accelerations of many test particles at rest at various locations of the frame in question. Obviously they can have different values of 4−acceleration, which is why I put "the" in quotes −− in that case there is no single 4−acceleration associated with the frame. I suppose the frame is "accelerated" if any of them have nonzero 4−acceleration.

You're probably not considering such subtleties. So let me ignore them and concentrate on tests for "accelerated" motion.

First I'll choose to interpret "accelerated" as having nonzero 4−acceleration: It's very easy to do: just release a test particle at rest relative to the coordinates to be tested, and watch whether it accelerates relative to them or not. If it does, they are accelerated; if it remains at rest then they are inertial coordinates. There are numerous other experiments that can determine this.

Now I'll choose to interpret "accelerated" as nonzero coordinate acceleration: your question is self−inconsistent because the "OR" is not valid: the surface frame is accelerated relative to the inertial frame, AND the inertial frame is also accelerated relative to the surface frame.

> For example, you made mention of the physical law F/m=a. Is this generally true in the surface frame?

It's not generally true at all, in GR, it is at best an approximation. There are, however, many interesting situations where it is far more accurate than experimental resolutions, so it remains useful in such situations.

> I think its an important
> question and their are experiments one can conduct (independent of the local inertial frames) which can answer this question unambiguously.

I'm not sure what question you want to answer. Whether "F/m=a is true in the surface frame" is known to be false in GR, in any frame.

> > When you say "gravity accelerates the object" you mean a coordinate acceleration using coordinates that are fixed to the earth (or similar).

> That's close enough for now.

> > This COORDINATE acceleration of the object is really an artifact of the coordinates, as any object at rest in them has nonzero 4−acceleration.

> Right. But then that is an artifact of a system of co−accelerating inertial frames.

How can an inertial frame be "co−accelerating" −− you are using words in an unusual way (inertial frames are by definition not accelerated).

> Keep in mind I am agreeing these object are moving
> by their inertia. I am qualifying that by saying that because of
> their inertia they are accelerated by gravity.

Hmmm. In GR, it is their energy−momentum tensor that makes them respond to gravity (i.e. the geometry of the manifold where the object is located). For a test particle this can be simplified to its mass.

I don't know what you mean by "inertia". I'll bet you
don't, either. Note that no theory of physics since Newton
has any quantity of any equation that corresponds to inertia.

> Because the system of
> inertial frames and the surface accelerate with respect to each other
> it must be acknowledged that the coordinate relationship of
> acceleration is ambiguous (locally).

Hmmm. I guess so. (?...)

> For a local system of inertial objects, one conceives the 4−
> acceleration of the local objects is ZERO when and only when one
> removes the artifact of their co−acceleration (that artifact is their
> acceleration property wrt a field centered non−rotating inertial
> coordinate system).

There is no "when and only when" −− the 4−acceleration of a test particle moving inertially is zero. Period. In essence that's what we mean by "moving inertially" (the real meaning is that an inertial test particle follows a geodesic path, but an essential characteristic of geodesic paths is zero 4−acceleration).

If your objects are not test particles, then their 4−acceleration is essentially useless, and may well be meaningless....

> This is basically the same conceptually as "removing the gravity".

It is impossible to "remove gravity" −− the manifold inherently has some geometry, and that's what we mean by "gravity" in GR. If you change the geometry you have a completely different physical situation, and in general the "before" and "after" situations cannot be sensibly compared.

That's like asking "how does one compare red and blue if one removes all color?"

> It's a question of which is the dog and which is the tail. Is it the co−acceleration which makes the local domain inertial for freely falling objects ... OR ... is it the inertial relationship between freely falling objects in a local domain which makes them accelerate with respect to a gravitationally centered non−rotating frame of reference. The property of the objects to be inertial wrt to one other is limited in domain. Another way of saying it is that their motion is not a continuous function without the context of their acceleration wrt to the gravity centered inertial frame.

All this is answered in GR: gravity is GEOMETRY, and locally−inertial frames at a given point are just the Riemann normal coordinates there. Inertial motion (for test particles) is a property of the geometry at their location, not of the test particles themselves. Of course the geometry is determined by the masses and other energy present throughout the manifold (universe).

In particular, "inertial motion" is not a "relative term" −− it is completely determined by the local geometry of the manifold.

>> In GR we do not normally attempt to discuss work, because it is exceedingly complicated and not very useful [#]. That's primarily because work is a type of energy, and energy is ALWAYS coordinate dependent; re−read my caveat about coordinate−dependent quantities above. In short, once one studies GR in any detail, it becomes QUITE CLEAR that whenever possible, one wants to discuss invariant quantities,

> > not coordinate−dependent ones.

> It is quite easy to discuss work in gravity but it is IMPOSSIBLE to make it coordinate independent. So what does that mean? It means that gravitational work IS NOT coordinate independent.

Of course. Energy is not coordinate independent, and work is a type of energy.

One corollary of this is that "gravitational work" cannot possibly be a valid model of some physical phenomenon. This makes it be not very interesting.

> One can't just
> choose any frame willy−nilly. There is a source of gravitational acceleration. The work done on a freely falling object would be related functionally to its inertial frame.

I don't know what you are trying to say. In a generally−covariant theory like GR, one can indeed choose any coordinates willy−nilly, and the equations of the theory will be valid in them.

The work done on an object depends on what coordinates you use to compute the work. As I said before, in GR work has thorns and is rarely, if ever, used. Work is an important concept in Newtonian mechanics; but as I also said before, it is not valid to attempt to transfer concepts from one theory to another.

Focusing on "work" is not a sensible approach to learning about GR. Nor is focusing on "gravitational force". One must learn geometry....

> > Remember that selecting coordinates is an ARBITRARY human choice, and such choices cannot possibly have any effect on physical phenomena.

> But nature doesn't always give us the choice. In that regard, nature isn't arbitrary. An object is the source of gravity. Effects are related to coordinate system of that source.

Nature has NOTHING WHATSOEVER to do with humans choosing coordinates. Nature QUITE CLEARLY uses no coordinates herself.

There is no "coordinate system of that source" −− you can choose many different coordinate systems in which the source is at rest, and if you compute "work" relative to them your will obtain wildly different values, some of which are zero and some of which aren't.

Do not confuse an object with a coordinate system. These are VERY different concepts.

Note, however, that the physical situation may very well suggest a particular coordinate system in which computations are easier or simpler. But this is merely a matter of convenience in computation, not principle as you seem to think.

> > Since I can make "work" appear or disappear
> > merely by thinking differently about the situation, it should
> > be clear that this "work" is unrelated to any physical
> > phenomena −−
>
> Absolutely false. One can't make work appear or disappear.

Sure I can. In the locally−inertial frame of a falling object, no work is done on that object. In the surface frame of the earth, gravity does work on falling objects. This is purely a change in point of view WITHIN MY MIND.

> He can
> choose the wrong coordinate system or select a class of coordinate
> systems where locally he can make work seem to disappear. Can you see
> what is wrong with the argument. You say a concept should be
> independent of coordinates and in same breath choose a class of
> coordinates "to make" a concept disappear.

There is no "wrong" coordinate system, because physical phenomena MUST be independent of coordinate system. So in a valid model of the world we inhabit, it cannot possibly matter what coordinates one chooses to describe physical phenomena −− ALL must be equally valid. Because nature does not use coordinates, and does not care about how humans CHOOSE to conceptualize and describe her phenomena.

It may well be CONVENIENT to select the coordinate system you have in mind. I certainly agree that computations in the earth−surface frame are quite useful for falling objects near that surface. But don't read anything more than computational convenience −− NATURE surely does not care (she makes no computations, her phenomena simply happen).

And the work you compute using those coordinates is at
best an approximation to something completely different.
NG is merely an approximation to GR....

> I mentioned earlier that tidal stress in the inertial body falling
> freely in gravity is evidence of work. Stress is clearly present
> within the tidally stressed object.

You mean strain. Strain is the deformation of an object in response to applied stress.

Note, however, that this is a completely different kind of work than we were discussing before. For this, one can easily identify energy in the inter−atomic electromagnetic fields that is the response of the object. For this to make sense at the level of this discussion one must abstract away quantum phenomena and heat, so this energy is most naturally described in the instantaneously comoving inertial frame of the object. This is far too complicated to discuss sensibly at this level....

The important point is: for the case of a test particle falling in gravity there is no comparable physical field that gains energy.

> Further if that object is a
> meterstick, guess what? It no longer has a connection to space−time
> with regard to its length (its longer than 1 meter of space−time).
> This has always confused me because if GR were purely geometrical
> wouldn't a meter−stick just curve with space−time always being the
> same length?

Yes, a meterstick does indeed respond to gravity, and if one is not careful it will deform. To avoid this one must arrange for the meterstick to remain strain free. This means you must support it all along its length, not just at one end. Or use it only when it is in freefall −− when moving inertially every pair of inter−atomic bonds will assume their normal distance, and one can safely use the ruler [#].

It is a challenge to make sure the ruler is in the
right place with the right orientation and at rest in
the right frame in order to make a given measurement....

[#] after any launch transients are damped out.

Fortunately one can measure the strain in the ruler and know whether or not there is a problem (and adjust things to eliminate it).

> Curvature as it is applied in GR seems more closely
> related to force or acceleration than geometry when one gives
> consideration to the effects of curvature. Why is it that the tidally
> stressed meter−stick loses its grip with space−time and no longer is
> extended one meter of space−time?

You need to learn how to think geometrically. Tidally−STRAINED objects are unsuitable for use as standards of length. You must arrange so they are strain free.

Tom Roberts
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