If Gravity Is Acceleration, Why Isn't Earth Exploding?

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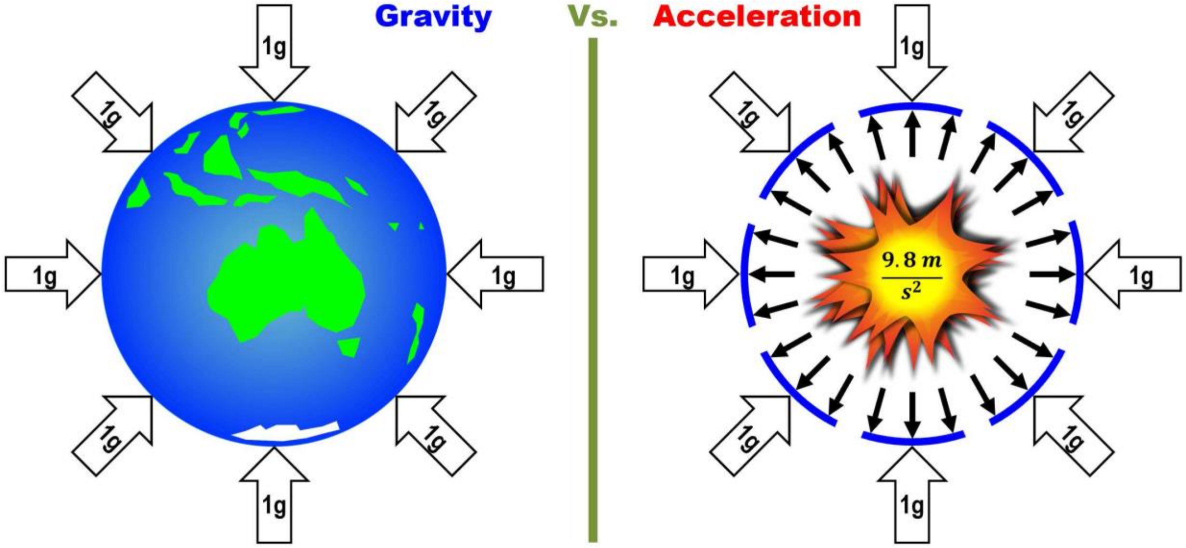

Einstein's equivalence principle famously identified an exceptionally deep insight: That the pull of gravity and the force exerted by acceleration are *the same thing*.

But you may have wondered: If that is true, why doesn't gravity add speed, momentum, and energy to your body since that is what happens when you accelerate in a vehicle?

It's a good question and one with surprisingly deep implications. The easier but less-than-satisfying answer is that it's all a matter of where you are looking from.

When a car drives next to you on a highway, you don't think of it as moving quickly relative to *you* (the special relativity principle). Similarly, as long as you are standing on the surface of the Earth, you cannot see gravitational acceleration adding energy to the person next to you because you are both accelerating at the same rate in the same direction (the general relativity equivalence principle). That means that if you do some test like bouncing a ball up and down between two plates — or light between ceiling and floor mirrors if you want to get fancy and precise — you *will* see the ball (or light) lose energy on the way up and gain energy on the way down. However, what you *don't* see is a net gain in energy by the ball (or light) over time. It always ends up a wash.

That seemingly small detail is a surprisingly important feature of acceleration, especially if you are curious about its relationship to gravity. For example, imagine you are in a room, elevator, or rocket undergoing smooth upward acceleration, and someone in the room asks you to devise a way to capture a bit of that tremendous acceleration energy to do something simple like powering a small lamp in the room. If you picture the power of that giant rocket beneath you, it sounds like a pretty plausible request. Surely, you think, there must be *some* way to capture a bit of that tremendous rocket power that you can feel pushing you against the floor of the room every second you are there.

However, try as you might, you soon discover that the request is very much akin to asking you to create a perpetual motion machine. Assuming the acceleration is perfectly smooth, you can *temporarily* add or subtract energy from objects such as bouncing balls, but you also discover that you can never *extract* energy from those temporary gains. The ensuing losses always cancel them out so that whatever energy you had in the room when you first began your smooth acceleration journey is what you are stuck with for the rest of the trip. You can use the acceleration to move the energy around in interesting and complicated ways within the room, in particular, alternating between cases such as when the ball is unmoving for a moment at the top of a bound (called *potential energy*) and its moment of fastest motion just before bouncing on the floor (*kinetic energy*). However, you cannot find a way to do anything more than shuffle the energy around.

Gravity as the Ultimate Smooth Operator

Notice that none of this is true for *irregular* acceleration! If you have an old-school self-winding watch — I love that those are getting popular again — you know what I mean. It's self-winding as long as it's on your *arm*, moving around in irregular accelerations in this or that direction. But if you just set it on your desk, gravity's smooth acceleration does nothing to wind it.

(As I write this, I see that the lovely self-winding watch on my desk that my son gave me this Christmas stopped an hour and a half ago for this reason! I can only wear it for short periods due to metal allergies. But it is a lovely device, easy to wind, and fun to, ahem, "watch.")

I'm making it a point to bring up *irregular* acceleration because I want to convey just how remarkable and specific the relationship between gravity and acceleration is. It is *not* the case that "any" form of acceleration is equivalent to gravity since *all* irregular forms violate energy conservation. Only incredibly smooth, uniform acceleration matches the properties of gravity as we see it on planetary surfaces that have undergone gravitational acceleration for billions of years.

That relation should bring a question to mind: If *only* the kind of acceleration that remains smooth and uniform for billions of years corresponds to the acceleration of gravity, how did one of the most fundamental features of the universe become so profoundly locked into one of the most difficult forms of acceleration imaginable? It is *not* easy to accelerate a large system in a straight line while perfectly maintaining the same acceleration, and you quickly run out of fuel or energy if you try it. Yet planets achieve this special case of acceleration trivially and with a level of perfection utterly impossible for jittery machine-implemented acceleration systems. Is energy conservation forcing gravity to take only the "paths" that follow the case of indefinitely smooth, no-net-energy-added acceleration? The answer is yes, but that's a general relativity question for another time.

Why Does Just Standing Around Not Get Me Excited?

While the unique no-energy-added properties of indefinitely smooth acceleration are important, a more perplexing aspect of gravitational acceleration is this: Even if gravitational acceleration adds no net energy to the *inside* of an accelerated room, isn't it still adding energy to a room as a whole, just as a rocket continuously adds kinetic energy to a space capsule, speeding it up to tremendous velocities? Or, more bluntly, if the entire surface of a planet is continually accelerating smoothly upward, why doesn't the whole silly planet blow up, no matter how smooth the acceleration is?

It's a great question! And like most great physics questions, it's surprisingly hard to answer without resorting to maths that may or may not help, depending on how familiar you are with them. But let's give it a shot to see how it works conceptually.

The answer must always begin with an observation: Planets *do not* blow up due to the upward gravitational acceleration of their surfaces, and planetary surfaces *do not* acquire nearly infinite kinetic energy due to their surfaces accelerating for billions of years. The stability of planets is an obvious but important clue that we've missed something.

The question to ask next is this: Is there *ever* a case in which gravitational acceleration at the surface of a stable planet produces real kinetic energy, just like rocket acceleration?

You likely expect me to say "no" about now, so you may be surprised to hear that the answer is… yes! Furthermore, it's a "yes" that provides additional insights into what's happening. But to keep from despairing over the details, we must first hit rock bottom — and I mean that quite literally, with a thought experiment.

An Especially Deep Physics Scenario

You are walking across a pleasant abandoned field with a soon-to-be-unfortunate physicist friend. Unbeknownst to either of you, the field was once a super-secret geological exploration site with lax safety procedures. Your friend unexpectedly steps into the world's longest borehole while you remain next to it. It will take him minutes to reach the bottom!

Realizing what has happened and being a dedicated scientist — plus knowing he's a bit short on options — he calls you on his specially instrumented walkie-talkie and starts chatting with you to report his experiences during his fall.

First, he notices that he no longer feels Earth's gravity — no acceleration. He gathers that the borehole was vacuum sealed, and he's still breathing only because a large bubble of air got sucked down with him. (Back at the top, you notice the same issue and brace yourself to keep from getting sucked in.) While not happy about the overall situation, your friend does find the opportunity to experience zero gravity quite intriguing!

The second thing he notices is that, based on Doppler effects on the walkie-talkie signal, *you are accelerating away from him* as you stand on the surface of Earth. You appear to be shooting upward like a missile, adding about 35 kph more speed every second!

The third thing he notices is that the *entire surface of Earth above him* is gaining energy relative to his new zero-gravity observation site. Your walkie-talkie radio signals down to him give the same data they would if you were on an actual rocket, showing that you are gaining energy and that the same bouncing-ball and bouncing-light experiments that formerly resulted in *no* net gain in energy are now showing a net shift towards faster and bluer. He can tell no difference. You're getting hotter from his zero-gravity perspective!

The observed energy increase bothers him since he knows that falling into a hole cannot violate energy conservation. He is, after all, seeing the *entire* surface above him accelerating, not just you. That's an awful lot of mass, acceleration, and energy! It was so much easier when he was at the top, thinking of such energy conservation issues from the perspective of watching one small rock fall into a hole instead of *being* that rock!

Just when he is about to despair, a resolution occurs to him: The massive energy release he is viewing is nothing more than stored (or *potential*) energy transforming, from his relative perspective, into moving (or *kinetic*) energy. The Earth stashed that energy away when it first formed, using the same springlike energy storage abilities that particle physicists call *Pauli exclusion*. Pauli exclusion is the same effect that gives atoms and molecules their size and keeps you from falling through your chair. He is seeing not *new* kinetic energy coming out of nowhere, but *stored* potential energy being converted — from his zero-gravity perspective only — into kinetic energy. The two forms are relative!

Surprisingly, he realizes that gravity is as real as rocket acceleration after all! He could not see its kinetic effects before dropping into the hole that released him from being mutually accelerated with the Earth's surface. As long as he had been in the same acceleration "room" as you at the top, he remained fully subject to the "no energy added" rule that applies to all forms of indefinitely smooth acceleration.

His next thought — one tends to think quicker than usual in such situations — was that he had gravity all wrong. He had always thought of the definition of gravity for a planet as absolute and stand-alone. Now, abruptly, he sees it differently: Gravity is a *relationship* between a large but finite stash of energy, often from billions of years ago, and hidden observers *not* subject to atomic matter's pressures and binding effects. Once these hidden viewers exhaust the entire stash of potential energy — if the hole were long enough to let him slow down and begin a return journey — the accelerations he observed would reverse, and the kinetic energies would return to their earlier potential states.

His final thought was this: If there was no Pauli exclusion — if he was over a black hole, for example — where *would* he finally land, and *when*? It kept him intrigued and busy.

There are worse ways to go!

Gravity and the Interplay of Energy

It's time to end, but the final point is this: The puzzling issue here is not the nature of gravity but of acceleration. Everyday experience fools us into thinking acceleration is always a relationship between two moving material objects. However, gravity examined closely tells us it is a relationship between stored forms of energy and odd observers *not* subject to the pokes and pushes of everyday matter and fields. When that more subtle view coincides with the bodies we see, we call this easier-to-view version "acceleration."

When the observer in question does *not* correspond to any obvious object — when only very special (or "bored"?) observers can witness acceleration transforming stored energy back and forth between its potential and kinetic forms — we call the outcome "gravity." That is not the end of this particular story, but it's a good start.