Mach's Principle, Inertia and Fruitcakes for the Hopelessly Befuddled

(No stinkin' Physics degree required)

by
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What it all boils down to is understanding what causes inertia, and exploiting certain characteristics of it to do neat things. Sort of like lawyers and loopholes. Now there are all sorts of equations and heavy duty physics that go along with this, but all that can make blood come out of your ears, which is viewed as "not a good thing" by normal folks. This explanation will forego all that, and just stick to the very basics. But remember, these are just the basics. Many significant details (not to mention just plain weirdness) are being glossed over in the interests of simplicity.

We'll start off with just what inertia is. When you push on something, be it a rock, a turkey sandwich or your pet poodle Fifi, you've noticed that something pushes back in a display of one of the most basic laws of nature. That "pushing back" you feel is the inertia of whatever it is you're pushing. But what precisely IS inertia anyway? Most people don't even think about it, they just accept that it's there (quite fortunately, in most cases). This is also true of physicists, even though in the popular imagination they're paid the big bucks to ponder mysteries such as this.

Back in the late 1800's a scientist by the name of Ernst Mach (of Mach number fame) came up with a clever and elegant proposal to explain inertia. He thought that the inertia of an object is the result of the gravitational effects of all other matter in the entire universe. Now that's a lot of matter! Eventually, this proposal picked up the label of "Mach's Principle", bestowed upon it by Al Einstein. Unfortunately, for various reasons it was rather hard to prove conclusively. Only in more recent times has theoretical thinking, along with development of Einstein's Theory of Relativity, led to means by which it appears likely that Mach was right.

One of the basic thought experiments for Mach's Principle has to do with a spinning bucket of water. If you take a bucket of water and set it spinning, the water gets low in the center of the bucket, and it tries to climb the walls. That's just the centrifugal force at work. Now here's the good part. Einstein's very well tested Theory of Relativity says all motion is relative: that you should get the same effect in the bucket if it is sitting still and everything else in the universe is spinning around it. The only possible way the rest of the universe, spinning madly around the bucket of water can possibly affect it is through some sort of gravitational interaction.

"Spinning water buckets are one thing, but how does some asteroid around Alpha Centuri affect the inertia of my Toyota?," you might be asking. Fair and interesting question. It turns out that every piece of matter in the universe creates its own little bit of a gravitational field. The value of this field at a distance is called the "gravitational potential". Taken by themselves, these little bits and pieces of matter around us don't amount to a whole lot, gravitationally speaking. Look how much matter you need in one place (i.e., the Earth) before anything interesting happens. And even then by simply jumping you can temporarily break the Earth's grip. Furthermore, this gravitational potential diminishes with distance, which is why our much larger Sun doesn't pull us off the surface of the Earth to a toasty doom. The much closer (though smaller) Earth wins the tug-of-war.

There is a similar situation with electrical charges worth mentioning. As you may be aware, things can have certain electrical charges. Materials can be positively charged, negatively charged, or have no charge. Things that end up having a positive charge simply have more positively charged "bits" than negatively charged bits. Things that have no charge, or neutral materials, have essentially the same number of positively charged bits as negative bits. The positive charges cancel out the negative charges. And neutral materials make up the vast majority of stuff in our universe, so when we step way back and look at our whole universe, the overall electrical potential is zero.

But this isn't the case with the gravitational potential, because there isn't "positive gravity" or "negative gravity" to cancel out each other. There's just one flavor of gravity and it adds and adds and adds and ..... Well, you get the picture. If every piece of matter in the universe is generating its own little bit of gravitational potential, pretty soon you end up with a huge amount of this gravitational potential everywhere.

But why don't we feel any of this gravitational potential if it's so great? Well, we do and we don't. In a sense, it's like living in a highly pressurized underwater habitat. Even though the occupants of the habitat might be under tremendous pressure, they don't really notice it because they experience the same pressure everywhere around them, even inside them. It's the same with gravitational potential. Even though it may have a very large value, as long as it's pretty much equal everywhere, we don't notice anything out of the ordinary. When we notice gravitational effects (e.g., falling down the stairs), what we're actually noticing are differences in the gravitational potential (the "gradient" in nerd-speak). In the case of falling down the stairs, it's the nearby Earth causing a gradient in the gravitational potential. But when it's the same potential everywhere, you don't feel it.

But I also said we do feel it. We "feel" it every time we push on something, and that something pushes back. It's the interaction of this universal gravitational potential with matter that causes inertia! The gravitational potential sort of "oozes" through all matter (because you can't shield gravity) and gives it that resistance to being shoved around we call inertia.

Oh yeah, and that Alpha Centuri asteroid? The gravitational potential it generates is a teeny, tiny part of the overall potential coursing through your Toyota and making it feel like a Toyota. Of course turnabout is fair play, and your Toyota generates a potential that acts back upon that asteroid. Pretty slick, eh?

"This all sounds extremely weird. What about those loopholes you mentioned?"

Well if you thought what we covered so far is strange, better tighten the seat belt. Let's take an arbitrary hunk of matter as an example, say your Aunt Edna's fruitcake. I'm sure you'd be willing to donate that to science.

If you just set the fruitcake on the table, not much happens. Now some might argue it's just the nature of fruitcakes, but there's more to it than just that. Sitting there, motionless, you could say that the fruitcake is "in sync" with the gravitational potential of the rest of the universe. In a loose sense, it is. You would also find this true if you gave it some constant velocity (and some may argue that giving fruitcakes velocity, preferably out a window, is a worthwhile thing). So, just sitting there or moving at a constant speed, what you have is just your plain, ordinary fruitcake. Nothing special going on, unless you have a fruitcake fetish. But let's look at the case where we accelerate the fruitcake (i.e., you change its speed). Actually, the most interesting effects happen from time-varying acceleration, but we'll just examine the simplest case.

So let's give our fruitcake a very, VERY rapid burst of acceleration and see what transpires. Skipping all the scary math, what happens is the fruitcake kind of gets "out of sync" with the gravitational potential it's immersed in. That's because the gravitational effects from all the stuff in the universe can only spread out at the speed of light and can't react to our rapidly twitching fruitcake. It's not like it's exactly outrunning it, but that's an image you can hold in your mind if you'd like. What you're actually doing is inducing a varying change in the fruitcake's position so quickly that the nice gravitational balance with everything else in the universe gets sort of temporarily mucked up. And since the inertia of the fruitcake is caused by this gravitational potential, if you can make the acceleration really, really large, the "muckiness" gets really, really large, and the fruitcake’s mass slightly decreases for the brief instant of this large acceleration.

Now we'll stop accelerating the fruitcake and let it just coast along for a bit at whatever constant speed it happens to be at. We now find its mass has returned to normal (ignoring any mass increase due simply to relativistic speeds).

Finally, we'll bring our high-speed fruitcake back to a stop via a huge deceleration equal to our initial huge acceleration. We note that the mass of the fruitcake gets slightly heavier during this deceleration, then returns to normal as the fruitcake plops to a stop. Overall, during the whole speed up - slow down cycle the unfortunate but well-traveled fruitcake goes through, the mass change averages exactly to zero, and you end up with the same mass of the fruitcake as if it were sitting still, so it's pretty hard to notice unless you carefully look for it.

But how does this take place? OK, time for an analogy of how this works. It's not a great analogy, but it's good enough. Picture yourself outside in an absolutely torrential rainstorm, holding a sponge. Happens all the time, doesn't it? Now think of the rain as the gravitational potential, and it almost instantly fills your sponge to bulging with a pound of water. The now-drowned sponge can't hold any more water than a pound, so the excess just bounces off or flows through it. Now start walking at a constant speed. A little water squeezes out as you first start off, but essentially the sponge stays fully saturated, and still weighs a pound. Now quit walking and start to move the sponge from side to side, slowly at first, but then faster and faster. What you're doing is accelerating and decelerating the sponge. You'll see that when you push on the sponge, it tends to squeeze or compress a little smaller and water squirts out, making the sponge a little lighter. Then when you pull back on the sponge, it elongates a bit and fills up with a little more of the "gravitational rain" and gets a little heavier. By doing this fast enough you can make large, but very temporary changes in the apparent weight of the sponge. Finally, when you get tired of slinging the sponge back and forth, and let it come to a rest, the gravitational rain fills it back to its normal pound. It should be noted that this extremely simple analogy makes use of plain, ordinary accelerations. Significant mass shifts require the use of varying acceleration.

It turns out this effect, while odd and interesting, is not terribly useful in itself. To get any really large mass shift, the amount of acceleration required is too huge to be practical. If you tried it with Aunt Edna's fruitcake, it would end up as fruitcake goo, a thought even more unpleasant than the fruitcake itself. So how the heck can you subject matter to large accelerations without pulverizing it?

Time for a little technical detour into the world of capacitors. A capacitor is just a bunch of metallic plates, separated by a small distance, holding a bit of electric charge. While a capacitor can hold a charge without anything between the plates, it turns out that placing an insulating material called a "dielectric" between the plates allows it to hold a great deal more charge. This dielectric has sort of a crystalline structure with the atoms arranged in neat, somewhat cubic cells. When the plates of the capacitor become charged, these atoms actually move a bit, like little weights on tiny springs, in response to the electric field. So when you charge and discharge the capacitor, you are actually moving some of the atoms in the dielectric back and forth very, very quickly. So via this method, the fruitcake, uh I mean accelerated mass, can be replaced by a rapidly charging and discharging capacitor. The faster it charges and discharges, the more "acceleration" the capacitor's dielectric atomic bits are subjected to and the larger the mass shift.

A significant problem with identifying this effect is how do you weigh something that's changing its weigh by a small percent many thousands of times a second, and just averages out to a zero weight change over a very small time? It turns out to be possible by giving the object rapid pushes against a very sensitive scale just as it gets lighter, and comparing those measurements to the weight when the cycle is exactly the opposite. How that's done in itself is somewhat interesting, but a variation of it can be exploited (remember that choice of words?) to produce thrust.

"Thrust? That sounds like something useful!"

You can actually get useful thrust using this effect when you sandwich the capacitor between two piezoelectric crystals. Piezoelectric crystals (piezos, for short) are a neat type of material that rapidly expands or contracts a small amount when subjected to a voltage and happens to be <u>very</u> similar to capacitor dielectric material. Most everyone's been exposed to them without being aware of it. Piezos are used in push button igniters for barbecues and other gas appliances (even cigarette lighters), in which case they work in reverse. By giving the piezo a swift whack with a spring-loaded plunger, the piezo generates a several thousand volt spark. Zap!

What we've done in the lab is taken discs made of piezo material, and placed them on each side of some capacitors. They're wired up to a voltage source that's changing around 28 thousand times a second, with one piezo wired in reverse of the other. This means that as one expands, the other contracts, and the capacitor sitting in between getting shuttled back and forth. The charging and discharging of the capacitor is synchronized with the motion of the piezos, so that the capacitor gets thrown one way as it gets slightly lighter, and then slammed back the other way as it gets slightly heavier.

To illustrate how that produces thrust, let's drag out another analogy. Picture yourself standing on a skateboard with a 10 pound brick attached to you via a bungee cord. If you throw the brick away from you, you and the skateboard will move in one direction and the brick will head in the opposite direction. Eventually the bungee cord will stretch to its limit, and you and the brick will stop, then come careening back together. If you note exactly where you and the brick smash back together (ouch!), you'll find it's exactly where you began. There was no net motion; it all balanced out. You didn't get anywhere and you got smacked by a brick, to boot.

Now let's say you replace your old fashioned brick with a new, high tech brick from Mach Industries. This is one great brick! As you hold it in your hand, it weighs 10 pounds. But then as you throw the brick away from you, its inertial mass drops to 5 pounds! When it stretches the full extension of the bungee cord, its mass has increased to 15 pounds. Finally, as the brick smashes back into you (sorry, we can't fix everything!), it's now back to 5 pounds. After you recover consciousness, you discover to your amazement you've moved some distance in the direction you first tossed the brick away from you. In this case, the forces don't balance out and there is net motion in one direction.

That's pretty much how we get thrust using capacitors and piezos. The capacitor is the brick, and the piezos are bungee cords. By doing it over and over many thousands of times a second, a net force (or thrust) can be produced.

"Are you out of your mind? This can't be real!"

It seems to be. The theory that says it should occur is pretty straightforward and is derived fairly simply from Special Relativity. When viewed in its entirety, it fits in with all other laws of physics. There's no new, strange physics required. In fact, some of the components are in published scientific papers going back to the 1940's and 50's.

It's been demonstrated in the lab in a number of different devices, and they all are fairly consistent. When subjected to rigorous checking, the effect is present when it should be and goes away when it's not supposed to be there. While this is very encouraging, the effect is still quite small, and the possibility does exist that this is all some bizarre quirk of the experimental setup. At the present, the possibility of it being a quirk appears fairly small and it looks to be the real deal.

It has not, as of yet, been definitely replicated by other experimenters. An experimenter named Robert L. Talley, doing research for the government in 1990, appears to have stumbled across evidence of this effect, but did not recognize it for what it could be, and didn't pursue it to any large degree. There have also been a few "informal" attempts at replication, with null results. This isn't surprising, as it turns out there are a host of subtleties and complications that make it a difficult experiment to do properly. If the necessary precautions and safeguards are not taken, a null result is almost guaranteed.

Better understanding of the effect and its workings has grown to the point where it’s now possible to actually make a device visually move on a pendulum arrangement. This has been done with several test devices in two very differently designed pendulum setups. Both of these have produced consistent, positive results.