Hi this is Steve Nerlich from Cheap Astronomy www.cheapastro.com and this is *Some observations on speed and energy.*

Here at Cheap Astronomy we do try to maintain some semblance of order. There's full Cheap Astronomy episodes and there's snippet episodes – which subsequently get turned into Dear Cheap Astronomy episodes. Well OK, there's also occasional interruptions from me banging on about my PhD, which isn't even about astronomy, but otherwise the Cheap Astronomy portfolio does strive to make some kind of sense.

Except, here I wanted to do something that was supposed to be a snippet except it went on too long and I wanted to put in all this stuff that didn't even make the first cut. So, this was a snippet now remade into a full episode that arises from my regrettable propensity to pounce upon some very minor errors made by some of my favourite podcasters. This time it's George Hrab from the Geologic podcast who said this (sound byte).

Now as is always the case, I first wrote to George to point out the problem and, to give full credit to him, he did write back, in fact twice. But after two attempts, I realised that I was totally failing to get the point across – which was not to say you got it wrong, but instead to point the intriguing story behind why it was wrong.

There is empirical research to show that if you run you burn way-more calories (that is way-more energy) than you would do if you walked the same distance. And it doesn't matter whether you walk briskly or walk slowly – running is just a more energy-intensive form of locomotion.

Indeed, there is an almost linear relationship there. Over a distance of one mile – which is about 1.6 kilometres, for anyone outside the USA. If you walk casually you will burn a bit of energy, if you walk briskly over that distance you will burn more energy and if you run, you will burn way-more energy. So the simple statement that (sound byte) is just plain wrong.

This got me thinking about whether I had stumbled across a fundamental principle of physics, which is **does moving faster over the same distance always need more energy?** And actually I think the answer is no… or at least *almost* no.

While it's true that running a set distance does burn more energy than normal walking, if you do that strange Olympic race walk over the same distance, you will actually burn more energy than you would by running over the same distance – even though running is actually faster than race walking. So, really, much of the energy cost involved in human locomotion is about efficiency. With race-walking you have to tie yourself up in knots to go as fast as you can while always keeping one foot on the ground. With running you have less restrictions, but your muscles are still exposed to more impact-rebound stresses and your body has to switch to rapid energy production pathways. These biochemical pathways yield energy returns quicker, but are less cost-effective in the long-term.

So, given all those complications, what we really need is a thought experiment. Imagine a spaceship with an impulse engine – you push a button, rockets fire and you get 10 km/sec added to your speed. So push the button once, the engine fires and you find yourself moving at 10 km/sec, fire it again you are then at 20 km/sec. So this seems a clear indication that moving faster does always need more energy. Well, it kind of depends.

Moving through a frictionless vacuum at a constant velocity doesn't actually need any energy, you're just moving in accordance with Newton's First Law of Motion. So over a set distance you can move faster without needing more energy – since, you only need energy to accelerate up to faster speed, in accordance with Newton's Second Law of Motion.

The reason that you expend energy to maintain a constant velocity on Earth is that you are constantly fighting against all the equal and opposite reactions that arise from Newton's 3rd law. The ground is constantly resisting your natural tendency to plunge towards the centre of the Earth at 9.8 m/sec and the Earth itself resists any attempt you make to roll it beneath your feet and instead forces you to move forward over its surface.

So really, the question of **does moving faster over the same distance always need more energy** really depends upon the particular context that you find yourself in.

And having dealt with Newton's laws of motion, you are probably now thinking – what about relativity?

Well, first we need to deal with classical relativity. Imagine yourself running on a treadmill at 10 km/hour while a friend in the same room is sitting in front of the telly eating a packet of chips. Relative to the treadmill surface you are moving at 10 km/hr, but relative to your friend you are not moving at all and, without any effort, he can overtake you when he gets up to grab another packet of chips. **Does moving faster need more energy?** Well, it kind of depends.

So, here we come to something that definitely is a fundamental principle of physics. There's little value in comparing different speeds unless you clarify the frame of reference from which you are measuring those speeds. So, in fact the question, **does moving faster always need more energy** is an incomplete question unless you also clarify a frame of reference.

But, with that settled, let's now let's think about what happens when you go really fast and I mean really, *really* fast.

Let's go back to our earlier thought experiment, the spacecraft that has a button that fires the rockets that add 10 km/sec a second to your speed. If you just keep punching that button again and again, then according to Newton's Second Law of Motion, each new burst of energy will just keep adding 10 km/sec to your speed, indefinitely and infinitely.

But of course Professor Einstein told us that you can't have infinite speed, it doesn't make sense. You can cross the same distance, going faster and faster each time, reducing your travel time on each attempt, but eventually you will reach a speed where the travel time between two points reaches zero. When that happens you are moving at the fastest speed that is possible in the universe and you can't go any faster.

So, we have to deal with that. Newton' 2nd law says that the acceleration gained from firing your rockets is a function of force divided by mass. A distant observer watching your spacecraft approaching the speed of light, will see the spacecraft's engines burning energy (which is the force part of the equation), but achieving steadily decreasing amounts of acceleration. So that observer's answer to the question **Does moving faster always burn more energy?** will be a resounding yes. As the ship approaches light speed, huge amounts of energy seem to be needed to gain even a centimetre a second of more speed.

But that is just one perspective, remember this is relativity. If you now consider things from the perspective of someone on the spacecraft, every push of the button does actually bring the ship to its destination faster – even though that's because the destination just doesn't seem as far away as it was when the spacecraft was moving slower. So, for anyone on the ship, the 10 kilometre a second button seems to work just fine, it's just that the spacecraft keeps arriving at its destination before the spacecraft's speed ever reaches the speed of light.

And so, once again, we discover that pretty much everything in life, even walking and running, has something to do with astronomy.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website where we try to run so fast that we run into the future. No ads, no profit, just good science. Bye.