

THE PHYSICS OF EVERYTHING

Volume I



Gravity, Light *e*' Time

*Why mass makes gravity, why light never ages, and why your clock and mine will
never agree – explained without the math*

PHYSICS, WRITTEN DOWN

Gravity, Light & Time

Volume I of The Physics of Everything

THE PHYSICS OF EVERYTHING · VOLUME I

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Why mass makes gravity, why light never ages, and why your clock and mine will never agree — explained without the math

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Physics, written down.

GRAVITY, LIGHT & TIME

Volume I of The Physics of Everything. First edition, 2026.

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ABOUT THIS BOOK. The Physics of Everything is an independent physics-education project. Its videos and books explain physics in plain words, with thought experiments, and with honesty about what is not yet known. Quotations from scientists are taken from named published sources.

SAFETY. The “Try it” experiments use ordinary household items. Do them with care and adult supervision where appropriate; never look at the Sun, and keep away from mains electricity.

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How to read this book

Under almost every one of our videos there are comments like these: *“Hard to get your mind around this but you have to watch a few times.”* *“I’m 70.”* *“I’m not a physicist.”* *“I don’t fully understand why I like these... most of it I struggle to understand but it’s compelling.”* Many of you tell us you watch each video two or three times. We read those comments, and this book is our answer to them.

A video moves at its own pace. It cannot wait while you stop and think, and it cannot let you turn back a page to check what a word meant. A book can. This is the thing you can reread at your own speed, in your favourite chair, with a cup of tea going cold beside you. Each chapter is built around one idea, and our aim is that by the end of it the idea has clicked so completely that you could explain it to someone over dinner.

You do not need any mathematics. There are two or three equations in the whole book, each explained in words, and you can skip every one of them without losing the thread. What you need is curiosity and a willingness to imagine: a falling lift, a clock on a shelf, a pair of twins, a beam of starlight. Physics at its best is mostly careful imagining, checked against the world.

How the chapters work. Each opens with a question. Read the first page slowly; it sets the puzzle. Along the way you will find a dark box called *The key idea*: if you remember only one sentence from a chapter, make it that one. Boxes marked *What you were taught* / *Closer to the truth* gently correct popular ideas that are wrong or half-right. *Try it at the kitchen table* boxes are small, safe experiments using ordinary things, and they really work. The notes in the outer margin are asides, sources and

“check it yourself” pointers; you can ignore them on a first reading. Every chapter ends with *What to remember*, five lines you can revisit when you come back to the book.

Read in order, the first time. The ten chapters build on each other. Chapters 1 and 2 answer the question that has brought more people to our channel than any other, *why does mass make gravity?*, and everything later rests on them. After that, dip in wherever you like. A glossary at the back explains every special word.

Expect to be surprised, and expect honesty. Some of what follows will contradict things you were taught. Where the popular version of an idea is loose (“light experiences no time”, “black holes suck everything in”) we tell you the more careful version, because the careful version is usually more beautiful. And where physicists simply do not know the answer yet, we say so plainly. There are several such places in this book. They are the most exciting pages in it.

The spirit of the book, like the spirit of the channel, is simple: anything truly understood can be explained in plain words, and “I don’t know” is the beginning of every discovery. We have tried to teach that way on every page.

Thank you for watching, for your comments, and now for reading.

– *The Physics of Everything*



Nothing Is *Pulling* You Down

| *If gravity is a force, why can't you feel it while you fall?*

Hold an apple at arm's length and let it go. It drops. You have seen this ten thousand times, and you have been told what is going on: the Earth is *pulling* on the apple with an invisible force called gravity. That explanation is more than three hundred years old, it works astonishingly well, and it is not quite true.

Here is the strange thing to notice first. While the apple is falling, nothing is happening *to* it. If the apple had a tiny passenger riding on it, that passenger would feel no push, no squeeze, no weight at all. Every part of the apple, every atom of it, falls together, perfectly calm. The only moment anything is felt is the moment the apple meets the ground.

Compare that with a real push. When you shove a shopping trolley, the trolley feels it: the handle presses into your palms, the metal flexes a little, the groceries slide toward the back. A force that acts on an object is something the object can feel from the inside, because it acts on one part first and that part has to pass the push along to the rest. Gravity, while you fall, is not like that. There is nothing to pass along.

This chapter is about taking that small observation completely seriously. It is the thread that, pulled patiently, unravels Newton's picture of gravity and leaves something stranger and more beautiful in its place. By the end of the next chapter you will know the real answer to one of the most-asked questions in physics: *why does mass make things fall?* But first we need to be sure about what falling feels like. And the answer is: like nothing at all.

CHECK IT YOURSELF

An astronaut on the International Space Station is not out of reach of gravity. At about 400 km up, gravity is still close to 90% as strong as on the ground. The astronauts float because they are falling, all the time, around the Earth.

1.1

The happiest thought

In 1907 Albert Einstein was twenty-eight and working as a technical expert at the Swiss patent office in Bern. Two years earlier he had published his theory of special rela-

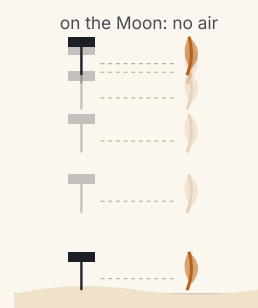
tivity, which dealt with motion at steady speeds. Now he had been asked to write a review article about it, and he was troubled. Special relativity said nothing sensible about gravity, and every attempt he made to fit gravity into it came out wrong.

Then, sitting at his desk, he had what he later called “the happiest thought of my life.” A person falling freely from the roof of a house, he realised, would not feel their own weight. For as long as they fell, gravity would, in a very real sense, have vanished for them. If they let go of a set of keys on the way down, the keys would hang beside them, falling at exactly the same rate. As far as the falling person could tell from anything nearby, they were floating.

That sounds like a small remark, the kind of thing you might notice on a fairground ride. Einstein saw that it was enormous. A force that disappears when you stop resisting it is a very odd sort of force. Electric forces do not do that: a charged balloon stuck to the wall pulls on some things and not on others, and you could tell from inside a falling room whether a magnet was nearby. But gravity treats everything exactly alike. Whatever you drop, whatever it is made of, it falls at the same rate as you do.

We have known this, in one form or another, for a long time. Galileo argued it four hundred years ago. (The story of him dropping balls from the Leaning Tower of Pisa comes from his student and may never have happened, but he did test the idea carefully with balls rolling down slopes.) The most charming demonstration was done on the Moon. On 2 August 1971, at the end of the Apollo 15 mission, the astronaut David Scott held up a geological hammer in one hand and a falcon feather in the other and let them go together. With no air to slow the feather, they fell side by side and touched the grey dust at the same moment.

Einstein described the moment in a 1920 manuscript on the development of relativity, published in *The Collected Papers of Albert Einstein*, Vol. 7. He told the same story in a 1922 lecture in Kyoto.



Apollo 15, 1971: a hammer and a falcon feather released together on the airless Moon land at the same instant. NASA's film of it is free to watch online.

On Earth, the air gets in the way, which is why we grew up believing that heavy things fall faster. Take the air away and the rule is perfectly clean. And “perfectly” is not an exaggeration. In 2022 a French satellite called MICROSCOPE reported its final result: two test masses of different metals, falling around the Earth together for months, kept pace with each other to about one part in a million billion. No other law in physics has been checked so finely.

Touboul et al., *Physical Review Letters* 129, 121102 (2022). The two masses were made of platinum and titanium.

1.2

A room with no windows

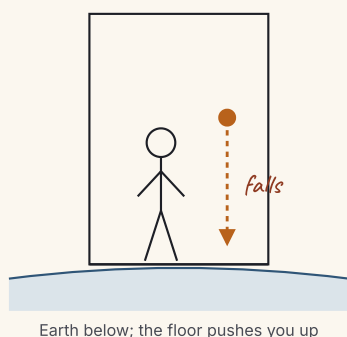
Einstein turned the idea around, and it became even stranger. Imagine you wake up in a small room with no windows. You stand on the floor, you feel your normal weight, and when you let go of a ball it falls to your feet. Are you in a house on Earth?

Or are you in deep space, far from any planet, in a room being pushed by a rocket that speeds it up by just the right amount every second? In the rocket, when you let go of the ball, it simply carries on at the speed it had. The floor, which is still speeding up, rushes up to meet it. From inside, that looks exactly like the ball falling. Your feet are pressed into the floor in exactly the same way, because the floor is pushing you along. Einstein’s claim was that there is *no* experiment you can do inside the small room, with balls or springs or clocks or beams of light, that will tell you which room you are in. This is called the *equivalence principle*, and it became the foundation stone of his theory of gravity.

Now notice what the two rooms have in common. In both of them, the thing you feel is the floor pushing up on you. In the rocket, that is obviously true: the floor is the thing doing the accelerating. Einstein’s insight was that it is equally true in your kitchen. When you stand on a bath-

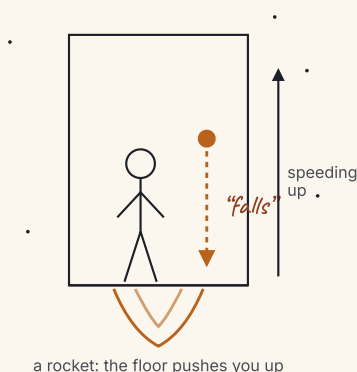
room scale, the number it shows is not gravity. It is how hard the floor has to push up on you to stop you doing what you would naturally do, which is fall.

A RESTING ON THE GROUND



Earth below; the floor pushes you up

B ACCELERATING IN EMPTY SPACE



a rocket: the floor pushes you up

Figure 1.1 Two sealed rooms. In **A**, the room rests on the ground. In **B**, a rocket pushes it through empty space, speeding it up by 9.8 metres per second every second. In both, a released ball drops to the floor in exactly the same way, and in both you feel the floor pressing on your feet. No experiment inside a small room can tell them apart.

THE KEY IDEA

The weight you feel is not gravity pulling you down. **It is the floor pushing you up.** Take the floor away and the feeling of weight vanishes, even though you are still right next to the Earth.

The equivalence principle has a consequence that Einstein spotted almost at once, and it will matter a great deal later in this book. Picture the rocket room again, and shine a torch horizontally across it. While the light is crossing the room, the room is speeding up, so by the time the light reaches the far wall, the wall has moved up a little. To someone inside, the beam has curved slightly downward, as if it were falling. The effect is tiny because light is so fast, but it is there. And if no experiment can tell the rocket from the planet, then the same must hap-

pen on Earth: *gravity must bend light*. In 1907 that was a wild prediction. Chapter 3 tells how it was tested, on a cloudy island off the coast of Africa, during an eclipse.

1.3

Falling around the Earth

If falling feels like nothing, then astronauts in orbit should be falling. They are. This is one of the most widely misunderstood facts about space, so it is worth taking slowly.

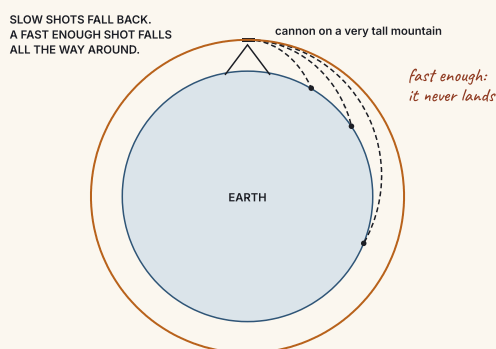


Figure 1.2 Newton's cannon, a thought experiment from his *A Treatise of the System of the World*. Fire a ball sideways from a mountain top and it curves down to the ground. Fire it faster and it lands farther away. Fire it fast enough and the ground curves away beneath it as fast as it falls: it falls forever without landing. That is an orbit. (Drawn to scale for a mountain a quarter of the Earth's radius high, which is rather taller than Everest.)

Isaac Newton drew a famous picture of a cannon on a very tall mountain. Fire a cannonball horizontally and it curves down and hits the ground some distance away. Fire it faster and it lands farther away. But the Earth is round, so the ground curves away beneath the ball. Fire it fast enough, and the ground falls away exactly as fast as the ball falls toward it. The ball never lands. It is still falling, every moment, but it keeps missing.

That is all an orbit is. The International Space Station travels at about 7.7 kilometres per second. In each second it falls a little over four metres toward the Earth, exactly as far as a stone dropped at that height would fall in its first second. But in that same second it also moves 7.7 kilometres sideways, and over 7.7 kilometres the curved Earth drops away beneath it by just about the same four metres. So it never gets any closer. It goes once around the planet in about ninety-two minutes, falling the whole way.

The astronauts inside are falling at the same rate as the station, so the station does not push on them, and they float. They are in a room with no windows that has lost its floor. Engineers call this “microgravity”, but that word is misleading: gravity is not small up there. What is missing is the push.

You can get the same feeling for a few seconds on Earth. Training aircraft nicknamed “vomit comets” climb steeply and then follow exactly the curved path that a thrown stone would follow. For about twenty to twenty-five seconds at a time, the plane and everyone inside it are in free fall together, and the passengers float. The plane is not escaping gravity. It is surrendering to it completely.

WHAT YOU WERE TAUGHT

Astronauts float because they are so far from Earth that gravity has almost run out.

CLOSER TO THE TRUTH

At the Space Station’s height gravity is still about 90% as strong as on the ground. Astronauts float because they and their station are falling together, around and around the Earth.

1.4

Where gravity hides: the tides

By now you might be suspicious. If gravity can be made to vanish just by falling, is it real at all? Could we explain the whole thing away as “the floor pushing”?

No, and the reason is the most important detail in this chapter. The equivalence principle works for a *small* room. Make the room big, and gravity gives itself away.

Imagine a falling room hundreds of kilometres wide. Release two balls near its left and right walls. Each one falls toward the centre of the Earth, but the centre of the Earth is in a slightly different direction from each of them. Their paths are not parallel; they converge, like the spokes of a wheel. So, as the room falls, the two balls drift slowly toward each other, although nothing pushed them. Release two balls one above the other, and the lower one, being a little closer to the Earth, falls a little faster: they drift apart.

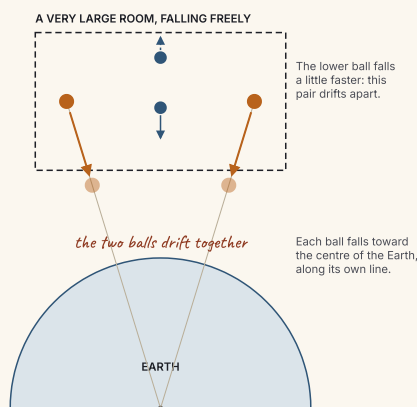


Figure 1.3 A huge room falling toward the Earth. Every object in it falls straight toward the centre of the Earth, so two balls released side by side slowly drift toward each other, while two balls one above the other drift apart. Inside a small room these drifts are too tiny to notice. They are the true fingerprint of gravity, and no rocket can fake them.

A rocket cannot produce these drifts. In a rocket, everything is pushed in exactly the same direction, by exactly the same amount. Only a real gravitating body, with a centre, squeezes things sideways and stretches them lengthwise like this. Physicists call these effects *tidal*, and the name is not an accident. The Moon does exactly this to the Earth. The oceans on the side facing the Moon are pulled a bit more strongly than the Earth's centre, and the oceans on the far side a bit less, so the water is stretched into two bulges, and the Earth turns beneath them. That is why most coasts have two high tides a day, not one.

So here is the honest version of the story. In a small room for a short time, gravity can be made to disappear completely. What cannot be made to disappear is the way gravity *differs* from place to place: neighbouring falling things drifting together or apart. That leftover is the real thing. In Chapter 3 we will see that Einstein gave it a name that sounds intimidating but describes it perfectly: the *curvature* of spacetime.

TRY IT AT THE KITCHEN TABLE

The weightless water bottle

You need a plastic drinks bottle, a drawing pin and a sink or a garden (this gets wet).

1. Make a small hole near the bottom of the bottle with the pin. Cover it with your thumb and fill the bottle with water.
2. Hold it up and take your thumb away: a jet of water shoots out of the hole, because the water above presses down on the water at the bottom.
3. Now simply let go of the bottle and watch the hole as it falls.
4. The jet stops. While the bottle falls, the water falls with it at the same rate, so the water no longer presses on anything. For half a second, inside that bottle, there is no weight.

That small experiment holds the whole chapter. The water did not escape gravity: it was falling harder than ever. What it escaped was the bottom of the bottle pushing back.

BY THE NUMBERS

9.8 m/s² How much a falling object's speed grows each second near the Earth's surface, whatever it is made of.

~90% Strength of gravity at the Space Station's height, compared with the ground. Astronauts float because they are falling, not because gravity is gone.

92 min Time for the Space Station to fall once around the whole Earth, moving at about 7.7 km every second.

10⁻¹⁵ How closely platinum and titanium were found to fall alike by the MICROSCOPE satellite: one part in a million billion.

1.5

Straight lines through time

If a falling apple feels nothing, maybe it is doing the most natural thing an object can do. In the seventeenth century Newton set down the rule for natural motion: an object left alone keeps going in a straight line at a steady speed. A hockey puck on smooth ice, a probe drifting between the stars. Things do not need a reason to keep moving. They need a reason to *change* how they move.

A falling apple does not look like a thing left alone. Its path through space bends, and its speed climbs. But here is the clever step. We have been drawing the apple's path through *space*. Physicists like to draw something else: an object's path through space *and time* together. Put height across the page and time up the page, and mark where the apple is at each moment. The line you get is the apple's whole life history at a glance. It is called a *worldline*.

A ball sitting still on a table has a worldline that runs straight up the page: same place, later and later times. A ball rolling steadily across the table has a straight worldline that leans over. And a falling apple has a worldline that curves, because its speed changes. On flat paper, the falling apple looks like a thing being pushed.

Einstein's proposal, worked out over eight hard years and published in 1915 as general relativity, was this: the paper is not flat. Near a heavy body like the Earth, the fabric of space and time is shaped differently, and on that true shape, the falling apple's worldline is as straight as any line can be. The apple is doing what Newton said natural things do. It is the ground, and you standing on it, that are being forced off the natural path, which is why you feel the floor's push all day long.



The falling apple's life drawn with time running up the page: its worldline. On flat paper it curves.

“

The falling apple is the most relaxed object in the universe. It is the ground that is under stress.

That is a big claim, and so far it is only words. What does it mean for time to have a “shape”? And how could a shape make an apple, which starts at rest, begin to move? The answer turns out to be something you could, with good enough equipment, check with two clocks: one on a shelf and one on the floor. It is the subject of the next chapter, and it is the real answer to why mass makes things fall.

A CONVERSATION

READER Hold on. If nothing is pulling the apple, why does it speed up? A thing at rest should stay at rest.

TEACHER That is exactly the right objection. A straight line through space would keep a resting apple resting. So whatever “straight” means here, it cannot be just about space. It has to involve time.

READER Time can be bent?

TEACHER Time can run at different rates in different places. That is the whole of Chapter 2.

WHAT TO REMEMBER

Chapter 1 in five lines

- 1 A freely falling object feels no force at all. Every part of it falls together.
- 2 The weight you feel standing up is the floor pushing on you, not gravity pulling.
- 3 In a small sealed room, standing on a planet and being pushed by a rocket cannot be told apart.
- 4 Gravity's true fingerprint is tidal: neighbouring falling things drift together or apart.
- 5 Einstein's idea: falling things move as straight as they can through spacetime; it is the ground that pushes us off course.

Next: why clocks on the ground run slow, and why that is what makes things fall.