Introduction

Why do things fall?
They don't drop from down to up, or from left to right.
If an object is not supported it will surely fall until it hits the ground.

The reason is, of course, gravity.
Gravity. The pull of the Earth. The attractive force.

But what if that attractive force didn't actually exist? If there's no pull, what causes objects to fall?

The answer to that question is an amazing one indeed.
It's time to unlock the secrets of gravity.

Chapter 1

All objects fall in the absence of support.
That is an everyday, obvious fact. But the reason they fall is far from obvious.
If you feel that 'things just fall' is not a good explanation, then you're starting to think like a scientist!

People have tried to understand gravity since ancient times. In the fourth century BC the greek philosopher Aristotle attempted to provide a definitive explanation.

He claimed that the universe was made up of five elements - earth, water , wind, fire and an unchangeable, heavenly element named aether. Earth, he said, was the heaviest element, and the more earth an object contained, the faster it would fall to the supposed centre of the universe beneath our feet.

According to Aristotle's theory, if we dropped a large stone and a sheet of paper from the same height, the stone would naturally hit the ground first.

Heavy objects fall faster. Seems intuitive enough, doesn't it? Of course, Aristotle must be right!
For almost two thousand years these ideas formed the basis of our understanding of gravity. Unfortunately Aristotle was wrong.

We had to wait until the sixteenth century and the appearance of Italian scientist Galileo Galilei for a correct description of the effects of gravity. Galileo discovered that heavy objects do not fall faster. He discovered, in fact, that without air resistance, all objects fall at the same rate of acceleration.

Galileo set up an experiment using balls identical in size but differing in weight. To reduce the effects of air resistance, he did not drop the balls, but instead rolled them down a slope.

The balls took exactly the same amount of time to reach the bottom. They fell at the same rate of acceleration, the same speed regardless of weight!

For almost two millennia it had been believed that an object's nature, its weight was fundamental to understanding gravity. Galileo proved this to be untrue. If the Earth had no atmosphere, a feather and an elephant would fall at exactly the same rate, and hit the ground at exactly the same time!

With Aristotle's theory disproved, gravity's true identity was again obscured. Galileo did, however, make other discoveries that would eventually lead to a better understanding of gravity.

Chapter 2

Place a cannonball into a cannon and aim it parallel to the ground. At the same time, take another cannonball in your hand and prepare to drop it from the same height. Then, fire one and drop the other at exactly the same time. Question: which one hits the ground first?

Perhaps many of you will reason that the cannonball fired from the cannon spends longer in flight, so the other, the one simply dropped, will hit first. Well, Galileo found that in fact both will hit the ground at the same time. Vertical motion due to gravity is entirely independent of any horizontal motion!

Galileo gave us an accurate description of the way objects fall. Two incredibly counterintuitive facts - neither an object's weight nor its motion parallel to the ground have any effect on the falling itself.

Now, what happens if we fire that cannon again, but this time increase its power so that the cannonball is travelling at a much much higher speed? Here's a hint - the Earth may look flat but it is in fact a sphere.

Over a certain speed, the distance the cannonball falls due to gravity and the distance the curved Earth recedes from it will become the same. The cannonball is falling, but not getting any closer to the Earth!

So what happens if there's no air resistance to slow the cannonball down?

That's right. The cannonball continues to travel its course and never lands. It goes into orbit, flying around and around and around the Earth. The cannonball is constantly falling, but because the Earth is a sphere, it will never reach the ground.

This is how all satellites orbit the Earth. And it's not just the artificial satellites. The Moon orbits the Earth and the Earth orbits the Sun in exactly the same way.

The first person to realise this was the English scientist Sir Isaac Newton, born in fact the same year Galileo died.

Newton reasoned that the force causing objects to fall on Earth was identical to the force that kept celestial bodies in their orbits, that the Moon, the Earth, the planets and the Sun were subject to the same force. The Moon falls around the Earth and the Earth falls around the Sun.

Newton suggested that all objects in space experience gravity, and therefore attract each other. He called this The Law of Universal Gravitation.

All objects, no matter how small, are sources of gravity. We humans are no exception. But the strength of the force depends greatly on the size of any object and the distance from it. If we approach an object the force of its gravity will increase. The more massive an object, the greater the force. The smaller the object, or the farther from it, the weaker the force.

It may come as a surprise, but gravity is actually an incredibly weak force, the weakest by far of the four fundamental forces. An example. Raise your little finger. Easy, isn't it? Well you've just succeeded in overcoming the gravitational force of the entire planet Earth with that one little finger.

Gravity is an unbelievably weak force, but without it the universe we know would not exist.

Chapter 3

You could call gravity a 'tiny giant'.

It's thought that the universe began with an explosion called the Big Bang.

The Big Bang was not a conventional explosion. Fragments did not explode out into empty space. There WAS no space. Space itself began to expand outwards. And under the influence of gravity, the material, the gas created in the explosion went on to form the stars and the galaxies that now make up the universe.

There were tiny differences in the density of the expanding gas, denser regions and less dense regions.

The denser regions exerted more gravity, and increased in density as they drew in more gas. The more massive they became, the more gravity they exerted, and the more gas was attracted inwards. They merged to form even larger regions. Gravity emphasized the patterns present in the early universe.

The denser regions grew further. The force of gravity at their centres became overwhelming, and temperatures and pressure rose incredibly. Over a certain tipping point, nuclear fusion began to occur - the birth of a star.

These were the first stars in the universe, balls of gas ignited by the force of gravity.

Gas and stars drew together and formed galaxies.
Galaxies attracted each other to form groups.
Galaxy groups attracted to form galaxy clusters.

Gravity worked on tiny differences in the density of a gas cloud to give rise to the universe we see today.

Then, four point six billion years ago, our Sun was born. Gas and dust not drawn into the Sun formed an orbiting disk. Dust particles merged and became objects several metres in diameter. Gravity brought these together to form objects kilometres across. Our planet Earth was born.

Gravity continues to move the universe. The birth of stars and planets, their form, their courses, and their destinies are largely controlled by gravity. Gravity plays a huge role in shaping our universe.

Chapter 4

Newton correctly identified gravity as a universal force and described accurately the influence gravity exerts on objects. But he had no idea how it actually worked.

Why do all objects in the universe mutually attract?
How can two objects separated by huge distances influence each other?
And how is the attraction transmitted across empty space?
There was still much to be uncovered.

Gravity. The force that shapes the visible universe. The force that without exception influences the tiny and the huge. What could possibly be its true identity?

We had to wait until the early twentieth century and the physicist Albert Einstein to know the answer.

We supposed there was a force between objects, a force that caused the objects to attract. Scientists gave this force the name 'gravity' and attempted to unlock its secrets. And that is the reason it took so long to figure out.

Why? Because the attractive force we call gravity does not actually exist! It took a true leap of imagination for Einstein to unmask gravity. And the answer he found was truly amazing.

It's time at last to reveal gravity's true nature.

This is a regular room. There's nothing at all special about it. Suppose I live here.

Let's remove the furniture. Okay it's empty. Oh wait, we forgot the air. Right now it really is an empty room, a vacuum. Let's also remove the light.

There is now nothing at all in this room. But the space, the emptiness surrounded by the walls is still there. That does not change.

This is the space we're going to talk about. We don't mean the planets or the stars or the galaxies. We mean space itself - the space you can't see but that exists everywhere. The space of an empty room, the space that acts as a container for everything else.

It turns out that this container is not just space. Space is inextricably linked with the fourth dimension, time, and the two together make up 'spacetime', the basic fabric of the universe.

Spacetime has a surprising attribute. It changes shape. Spacetime distorts.

And what distorts spacetime? Objects with mass. Our Sun, the Earth, even we humans. Just through existing, through possessing mass we distort spacetime.

It's a little difficult to imagine, isn't it. How can something that appears to be nothing change shape?

Let's put the time dimension to one side for a moment, and look at how space might deform.

Here's a trampoline. What will happen if we put a bowling ball in the middle? Of course, the trampoline will deform under the weight of the ball.

Now imagine that the trampoline is space and the ball is the Earth. Just the presence of the ball on the trampoline deforms the surface. Just the presence of the Earth deforms the space around it.

If we move the ball around the trampoline's surface, the distortion follows. It's exactly the same for the Earth moving through space. The Earth is constantly deforming the space around it. This is happening now, all around us.

Objects as large as the Sun or as small as a grain of sand, they all deform the space around them. The more mass an object has, the more distortion it creates. The Sun has a huge effect on the space surrounding it. A grain of sand hardly registers at all, but the effect is there.

Distortion due to the Sun reaches far out into the solar system. The Earth is responsible for less distortion and the Moon has an even smaller reach. All objects without exception warp the space around them.

You may be wondering why we're discussing the distortion of space when we should be talking about gravity. Well don't worry, it's time to reveal all.

What happens if we place two balls on the trampoline? A bowling ball and, say, a tennis ball. The smaller ball moves towards the larger one.

You could say that the tennis ball moved over the surface of the distorted trampoline, falling towards the bowling ball.

If the trampoline was invisible, it would appear that the smaller ball was somehow attracted to the larger ball by some mysterious force.

A scientist may give this mysterious force a name, may perform various experiments in an attempt to identify its true nature, may be puzzled when its cause eluded all explanation.

Is this all sounding familiar? You're right. This is gravity's secret.

The bowling ball is not attracting the tennis ball with some mysterious force. The larger ball is distorting the trampoline and the smaller ball is just following a path on its surface.

Until Einstein, it was this illusion of attraction that provided a barrier to understanding.

Distorted space is invisible. We experience only the effects. Objects that fall on Earth are merely following a path through distorted space. Orbiting moons and planets are also just following a path, falling along a line in distorted space.

Gravity is not a force that mysteriously attracts across distance. It is the natural consequence of objects distorting the space around them.

The Earth is not attracting us. We are endlessly falling into the distortion created by Earth's gravity, and the ground is stopping our descent.

Look around you. All things really do distort space. We can't, of course, see it. But imagine .... the space around a coffee cup, around a potted plant. Around us. The distortion is tiny, but it really, really exists.

It's a strange and wonderful universe, with space a fluid, distorting fabric around us. But it doesn't stop there. To simplify things, we've dealt only with space. In reality, that distorting fabric of the universe is actually 'spacetime', an inseparable fusion of space and time.

And importantly, space and time distort together as one. That's right, time is also fluid. Time also distorts.

As with space, the more mass an object has, the more it distorts time. The closer you approach, the slower time will flow.

When you are on a plane, time passes more quickly than at ground level. The difference is tiny but measurable and has been confirmed by experiment.

A universe where a distorting unseen spacetime governs the movement of objects and the passage of time. It's no wonder gravity took so long to explain.

Ending

Gravity revealed. Not as a force attracting all objects, but as a fundamental property of the very fabric of the universe. Stars and planets in perpetual motion through eternally distorting space and time. Gravity drawing all together, giving shape to what we can see.

It truly is a strange and wonderful universe.