

Scientists who vetted chapters in their subjects

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AUTHOR'S NOTE

YOUNIVERSE is a short introduction to the basics of modern science. It's also a travel guide. It describes in simple terms the world you are inseparably a part of: what it is, how it works and, most importantly, your place in it – insofar as these things are known. It's the book I wished for when I first made this journey myself.

The Big Bang, matter, energy, particle physics, biology, evolution and the future of technology are the subjects. Plain speech, short chapters, digestible chunks of information, absence of scientific terms and equations are the style.



Science is a realm of marvels. You are going to travel through time and space – a world of the unimaginably big and the inconceivably small. So it's important to take your time. The book is short, but the universe can't be swallowed in a day. The information is, I hope, clear cut, but as with any travel guide, there's a lot of it, and some bits may need review, if they are going to stick.

Our brains are filters. Faced with new input they can balk like a skittish pony refusing a jump, or slam shut like a clam. So here's a tip. Best to digest a chapter at a time. If something seems difficult, take a break and make another run at it. Maybe read the bare-bones summary at the end of the chapter, then read the 'difficult' bit again. Suddenly the fog will lift and it's perfectly clear. The words haven't changed, but your brain has. Rereading has allowed it to lay down references, find some connections and ready itself to fit in brand new material.



All the chapters have been vetted by distinguished professionals in each field and any errors are my own. My aim has been to present the topics clearly, and to smooth the reader's path by making them accessible and also entertaining. I enjoyed researching and writing this book enormously. I hope it shows, and that it's infectious.

PREFACE

In the beginning, some 14 billion years ago, there was a massive ‘explosion’ and the universe was created – or, more precisely, it became a work in progress. Some cosmologists believe that this event, the Big Bang as it’s called, wasn’t unique. Rather it was one of several sequential big bangs, as one universe succeeded another, like a series of exploding Russian dolls. Our universe is merely the current one, or possibly one amongst many in a vast incomprehensible multiverse. Others think the universe may have been reborn – so having previously existed it collapsed in on itself, then rose again like a reseeded plant or indomitable bouncing ball. A few claim it popped out of a Black Hole, while a number maintain God’s finger was on the trigger, firing once or repeatedly over time.

Although scientists are conflicted over these first micro-fractions of a second, they generally agree the Big Bang released an infinitesimal hyper-dense concentration of energy and matter that, over billions of years, clumped together to form the stars, planets and galaxies of our universe, and eventually ourselves.

A short account of how this happened, the structure of stars and matter, the mysterious arrival of life and emergence of human beings, the interconnectedness of all things on the planet, and your place in it, is, as has been noted, the subject of this book.

Why bother, people often wonder. It’s hard enough to keep track of everyday news and goings-on. There’s just more information around today than we can possibly assimilate. Renaissance man knew most of what there was to know because it wasn’t much. We have to rely on experts: doctors for our bodies, psychiatrists and neurologists for our brains, mechanics for our cars, computer gurus for electronic devices, and astronauts,

cosmologists and sci-fi for outer space. The only expertise we lack and really long for is a robotic domestic staff.

Having bought this book, however, you may feel differently. You may be curious. We humans are by nature pattern-makers and puzzle-solvers. Curiosity and wonder are innate; so is the desire to learn. What's more, we like to influence, even dominate our surroundings, animate and inanimate, and to chatter, sometimes responsibly, about debated issues. The more adventurous young may yearn for daring undertakings and new worlds to discover, even conquer. Science is where that territory lies.

Would you move into a house with no idea what it is made of or how the things inside it work, as an insect or a mouse might do? The universe houses you in one tiny corner. You are made of its material. You are 100 per cent dependent on it for food, warmth, light and body repairs. Every few years your body is replaced by new material from the universe, which with uncanny accuracy is customised and fitted into place, following a pattern dictated by your genes. You are a cell in the universal fabric. And when you die, you'll be absorbed back into the universe.

But right now, amazingly, you are quasi-separated from the universal blend. You are *you*, able to have a look around, take in the protean world you are a part of, possibly make some changes to it and at the same time learn something of what you are, who you are and where on earth you and your genes are going. You have five senses and the precious gift of consciousness with which to make the most of life, while you can.

What Are You?



1

GENESIS

'It is the stars, the stars above us, govern our conditions.'

Shakespeare, *King Lear*

Some 13.8 billion years ago the future universe was a tiny speck, a fraction of the size of a nuclear particle. It was densely packed and incredibly hot. Suddenly out of this over-heated nano-egg burst a fireball that, in the blink of an eye, had doubled in size 100 times or more and created the basic building materials for every object in the universe, as well as time and space.

Within one 10,000th of a second after the Big Bang, when the ballooning fireball's temperature began to fall, the universe had become a chaotic mass of seething radiation (light) and subatomic particles colliding and annihilating each other in a violent particle war that lasted for the next 380,000 years.

By then, things having simmered down to about the temperature of the sun's surface today, the tiny warring particles could begin to stabilise and come together. The stars and planets began to form.

STARS

The first stars appeared some 200 million years after the Big Bang. They were formed inside dense clouds of hydrogen gas and dust, the primordial soup of the early universe. Their evolution took millions of years, but within a few minutes of the Big Bang, vast clumps of hydrogen gas were being squashed into balls of helium

by the pull of gravity. The process releases, as a kind of exhaust, energy in the form of heat and light. This is nuclear fusion. It keeps stars hot and shining. It can also make nuclear bombs.

Stars keep their stability by balancing the outward push of nuclear energy and the inner pull of gravity. But when the hydrogen that fuels a star runs short, the star begins to lose its balance. Eventually gravity wins and the star collapses in on itself or, if it's really big, explodes.

The earliest stars were truly gigantic – hundreds of times bigger than our sun. But being unstable they were comparatively short-lived – and hugely beneficial. Most of the elements in the universe were cooked inside them. When they exploded, they spewed out the building materials for generations of new stars, plus the essential *carbon, nitrogen, oxygen* and *iron* inside you and everything around you.

Stars are the mothers of the universe. You too are stardust.



Our **sun** is one of a 100 billion stars in the Milky Way galaxy. Some 5 billion years ago, clouds of hydrogen and dust, spinning faster and faster under gravity, flattened into a disc. Most of the material, ‘gravitating’ towards the centre, combined as described above to make the sun. The remaining material, swirling around the baby star, became the planets, moons and asteroids. Too small to be light-producing, they settled for a reflective glory.

Today, the sun’s molten core is roughly the same temperature as the universe when a few minutes old. Much of what goes on inside it is also the same. Nuclear fusion keeps the gases hot and under enormous pressure. This releases radiation in the form of light. Light takes thousands of years to get from the sun’s core to its surface. A lot of dodging and crashing about happens en route. But once the rays break free, they reach the earth, 150 million kilometres away, in only eight minutes.

Our sun has already used up half its hydrogen fuel. This means it’s halfway through its lifespan. Once it can no longer keep up its hydrogen-versus-gravity balancing act, it will implode. When this

happens, its contents will be dumped back into space and recycled to make new stars. But no one will be around to see it.

ENIGMA

In 1998 an extraordinary discovery was made. Cosmologists suddenly observed that the universe was expanding, *really* fast. What's more, the *rate* of expansion was accelerating, the galaxies growing further and further apart. In short, gravity wasn't doing its job: things were flying apart instead of pulling together. Scientists were confounded. Could some other, stronger force or governor be at work? Nobody had a clue. Yet something was overpowering the dominant force of gravity.

Dubbed *dark energy*, the mysterious force joined an earlier proposal of an equally mysterious *dark matter*, which, giving out no light, was invisible. Just as dark energy may account for the universe flying apart, dark matter may have helped to pull it together in the first place.

Names make us feel more in control. But the fact remains that in spite of all we've discovered about the universe so far: its trillions of stars and galaxies – what they are made of, how they tick and so much more – something strange and utterly different is out there. And it's enormous.

As a result, the universe's composition has been radically revised: 73% is deemed to be dark energy and 23% dark matter. In other words, only 5% of the universe is known to us. As we are ourselves made of ordinary matter, dark energy and dark matter are for now beyond us in every sense.

To summarise:

- The known universe is 3/4 hydrogen and 1/4 helium. However, only 5% of the whole universe is known to us.
- Stars are hydrogen-fueled nuclear furnaces. Most of the elements in the universe were cooked inside them over millions of years.

- When a star dies, its heat-forged elements spill out into the universe and are recycled.
- Stars created each other and almost everything in the universe, including you.
- Dark energy and dark matter make up most of the universe. Recently, dark matter's presence was 'mapped' by bouncing starlight off it. We still don't know what it is.

2

MATTER AND MORTAR

'Bishop Berkeley said there was no matter, so there was no matter what he said.'

Lord Byron

If Bishop Berkeley had a viable point, it wasn't exactly the one that he was making. (But we'll get back to that.) Matter as we know it means the stuff of every known thing in the universe: microbes, insects, plants, animals, people, machines, mountains, oceans, planets, galaxies – everything that is physical. Matter is material. It's anything that has mass and occupies space. But what is that, when there are so many different kinds?

In the fourth century BC, the Greek philosopher Democritus divined that everything in the universe was made from combinations of a single indivisible grain. He named it *atomos*: indivisible. (He may have picked the idea up when visiting India.¹) Atoms, said Democritus, had no quality other than shape. They continually pushed and pulled each other about and joined up in different ways to make different things. They were like an alphabet, where joining the same letters up in different ways produces myriad stories and expressions.

Two thousand years later, in a brilliant piece of mathematical thinking, the young Albert Einstein confirmed Democritus' theory. Everything was indeed composed of tiny particles that form the basic building blocks of the universe.

That was in 1905. Since then we've had a closer look, and although atoms remain the universal building blocks, they are not in fact indivisible. We now know that every atom is composed of

three subatomic particles: **protons**, **neutrons** and **electrons**. The protons and neutrons are bound together in a tight central *nucleus*, as shown (p. 8). They are themselves composed of three even tinier particles called **quarks**. Electrons, lightweight but hugely significant outliers, surround the atomic nucleus.

Atoms normally contain an equal number of protons, neutrons and electrons.

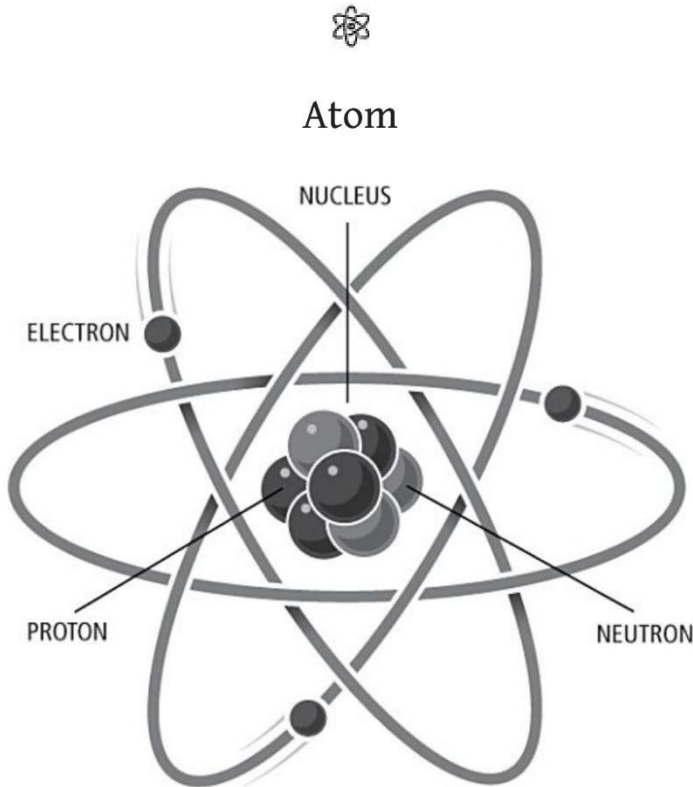


Figure 1 An atom, the basic building block of matter, consists of a nucleus surrounded by electron particles.

The atomic world is micro-minuscule. An average atom's width is 100,000 times thinner than a human hair. And in case you're wondering, an estimated 5 million million hydrogen atoms can fit on the head of a pin. What's more, if an atom were magnified to the size of a football field, its nucleus would be the size of a pea. Unlike football stadiums, however, atoms are 99.9% empty space.

Most importantly, atoms have an *electrical* aspect. Protons are

positively charged, electrons are negatively charged. Neutrons, as the name suggests, are neutral. They add mass. Since positive and negative charges cancel each other out, the atom itself is neutral and, therefore, *stable*. It can interact with other atoms and larger structures can be built.



All atomic building blocks need mortar to hold them together. This is the job of **four fundamental forces** (believed to have appeared in the Big Bang).

And that's it. Basically, every thing on earth is an assembly of three quarks and some flighty electrons held together by four fundamental forces. That's you in meltdown. Built up, however, your body consists of several billion, billion, billion atoms, all of which, remember, are 99.9% empty. And most of them are replaced every year.

BUILDING MATTER FROM SCRATCH

How can a few simple particles account for the complexities of a human body, let alone every object in the Universe?

It works like this. Atoms come in different types. A collection of one type of atom is called an **element**. Its *number of protons* determines what element the atom is, and therefore what material it will make. For example, if an atom has 6 protons it's a carbon atom, so it builds carbon material: diamonds are pure carbon. If an atom has 7 protons it's nitrogen, and 8 protons it's oxygen.

There are 118 known elements in all. Each has its own name, mass and size, and all are arranged according to their number of protons in a list called the periodic table, which is every chemist's bible.

Your body is made of zillions of atoms, but only some 40 elements. As described in Chapter 1, these were pressure-cooked in stars 5 billion years ago and released into space when the stars exploded. They entered your body mainly through breathing, eating plants, and eating animals that have eaten plants.

A bonded group of *different* elements produces what is sensibly

called a **compound**. Carbon dioxide is an example. Each molecule has 1 carbon and 2 oxygen atoms (written CO₂). Elements and compounds build all matter.

A closer look

Matter has three states: solid, liquid and gas. Three features are crucial in building it: the *four fundamental forces*, mentioned above, *chemical bonding* (glue) and the bizarre, hugely important but crazy behaviour of *electrons*.

THE FOUR FUNDAMENTAL FORCES

The four fundamental forces drive the universe. Each has a 'chariot particle' to carry it around.

The **strong nuclear force** holds the atom's quarks and its nucleus together. It's thousands of times stronger than gravity – at extremely short distances. Its chariot-carrying particle is called a *gluon*. Only quarks and gluons feel the strong force.

The **weak nuclear force** affects all matter. It helps fuse hydrogen to make helium in the sun. (Doing so, by the way, releases tiny particles called *neutrinos*. Billions are passing through your body as you read this.) The weak force also contributes to things falling apart (see *radioactive decay*, page 196). It's carried by particles called *W* and *Z bosons*.

The **electromagnetic force** combines all the electrical and magnetic forces. It keeps electrons inside atoms and helps link atoms to make larger structures. It's carried by *photons*, the basic units of light.

Gravity, the most familiar force, pulls bulk matter together. It caused the stars and planets to form and the reputed apple to fall on its discoverer Isaac Newton's head. Its chariot particle, the *graviton*, is in fact theoretical, having so far never been sighted. If it doesn't exist, it could seriously upset theoretical physics.



Chemical bonds glue atoms together. The job is done by flibbertigibbet electrons. So, before proceeding, let's take a look at these pivotal subatomic particles.

Electrons are almost beyond belief. The little critters are virtually weightless. They are only .01% of an atom's mass, they have no measurable position and they only show themselves, or arguably even exist, when interacting. Yet we know quite a bit about them, and their behaviour is crucial to chemistry, biology and the diversity of matter.

Continuously in motion, even spinning in more than one direction at the same time, so it's claimed, electrons inhabit so-called 'clouds'. These surround the nucleus, at fixed distances, rather like planets orbiting the earth. Each cloud has a particular energy level and holds the number of electrons suited to the atom's element. Only the electrons located in the cloud furthest from the atom's nucleus – the outermost or *valence* electrons – are involved in bonding.

CHEMICAL BONDS

Chemical bonds have two main types: *covalent* and *ionic*.

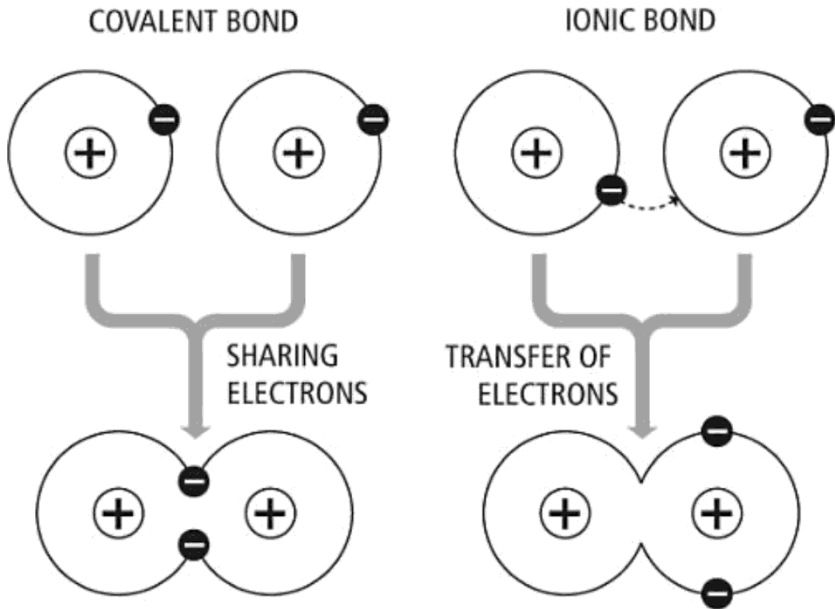


Figure 2 Covalent bonds are made by two atoms sharing an electron. Ionic bonds are made by transferring electrons from one atom to another. The black circles represent electrons, which are negatively charged.

Covalent bonds build both elements and compounds. They occur when two atoms, each one *sharing* an electron, make an overlapping bond, as shown in the diagram.

A **molecule** is an element or compound of atoms *joined by a covalent bond*.

Ionic bonds are made by *transferring* electrons from one atom to another, as shown. This builds **ionic compounds** (ionic compounds are never molecules). But what is an **ion**? It's an atom with a different number of electrons to protons – hence electrically charged, and unstable. But the advantage is, since opposite charges attract, other ions are keen to bond with it. This facilitates building matter. An atom's readiness to rearrange its bits to form molecules and ionic compounds makes an endless variety of new materials possible.

To recap: matter is built by joining the same type of atoms together to make an *element*. Or by joining different elements

together to make a *compound*.

Bondage: before new bonds can form, the old ones must be broken up. This uses energy stored in the bonds themselves. But – and this is important – breaking a bond can release more energy than is needed to remake it. Suddenly, free energy is available for other uses, as you’ll see in the next chapter.

To summarise:

- Four fundamental forces, carried by special chariot particles, govern the universe.
- Atoms, the basic building blocks of matter, are composed of three quarks and some swirling electrons.
- A stable atom is electronically neutral. It has no charge.
- Atoms come in different types called elements, defined by their proton numbers. Most elements were cooked in stars, billions of years ago.
- When *different* types of atoms are joined, they make a compound.
- Atoms are joined by chemical bonds. This involves giving, taking or sharing electrons with another atom.
- Breaking a bond can release free energy.
- Chemical bonding of elements and compounds enables the build-up of all known materials and creates the possibilities for new ones.

¹ The concept, attributed to the Hindu sage Aruni, appears in Upanishad texts from 800 BCE.

3

MOVERS AND SHAKERS

'What goes up must come down.'

(Attributed to Sir Isaac Newton)

In 1513, coming upon the Pacific Ocean, Vasco Nunez de Balboa waded right in and claimed the new-found sea for Spain. This sounds barmy, or at best an overzealous wish to curry favour with his powerful king. But Balboa knew that seas are valuable. They provide food and also roads that never need repair. And had he not completely lost his head, this indefatigable conquistador may have thought of looting China next. But decapitation intervened.

Balboa was an exceptionally energetic man, and the Pacific Ocean is, despite its name, an exceptionally energetic ocean. That animate and inanimate things should both possess energy may give pause. That every object in the universe, even a stone, possesses it, can beggar belief. But it is so.

ENERGY

Energy is defined as the ability to do work – to cause movement and to make things happen. In that respect, it's a mental construct. And with a bit of thought you might have reached the same conclusion. But there is more to it than that.

First, energy cannot be created or destroyed; it is conserved forever. This is a law of nature.

Second, energy is interchangeable. It's an invisible shape-shifter capable of taking several forms, which can be *transferred* and/or *transformed* from one into another.

Chemical, radiant (light), thermal (heat), mechanical, electric and nuclear energies are all familiar terms. But overall, energy has two basic categories: **kinetic** (moving) energy and **potential** (stored) energy. Every object has both.

Here's an example. The food stored in your body contains *potential energy*. When you use some of it to move about it becomes *kinetic energy*. If you kick a ball, your kinetic energy is transferred to the ball. As the ball goes through the air, friction causes it to lose some energy. When it stops, any energy left in the ball is stored as potential energy, until it hits something else.



There are swings and roundabouts as energy moves from one place to another, often changing form en route. For instance: corn eaten by a chicken is stored as potential energy for the chicken to move and grow. If you eat the chicken, its meat is broken down by your digestion and stored as potential energy for you to move and grow.

While this is going on you breathe in oxygen and exhale carbon dioxide. The carbon dioxide is absorbed by plants, e.g. the corn.

With the help of chlorophyll and water, the sun's rays (**solar energy**) shining on the corn's leaves, converts the carbon dioxide into **chemical energy**, so that the corn can grow – and provide more chicken feed. During this process, called *photosynthesis*, the corn releases, as waste, the oxygen you inhale to stay alive.



All the energy stored in your body comes from plants, or animals that have eaten plants. It began as solar energy formed by nuclear reactions in the sun's core at least 100,000 years ago.

Plants are the go-betweens. Their direct link with the sun makes them arguably the most important living things on earth. They, almost uniquely, make their own food. All other living creatures depend on them for oxygen and food. In short, for life.

A closer look

Balboa's energy, like ours and the chicken's, was **chemical energy**. Chemical energy is stored as potential energy in the bonds of molecules and compounds, described in the previous chapter.

The Pacific Ocean's energy comes straight from the sun, as **solar energy**. The sun's rays can warm the water's surface and the temperature difference between surface water and the cooler water beneath causes friction that releases **thermal (heat) energy**. In the tropics this is potentially powerful stuff. It's been said that only a small percentage of the energy trapped in oceans could one day power the world.

Today, the oceans' waves are used by power plants to make the **mechanical energy** that generates the **electrical energy** to light your house and run your computer, dishwasher and TV.



Many forms of energy – electrical, for instance – need a conductor to carry it. Others, like radiant (light) energy, don't need to hitch a ride. Light travels through space independent of matter.

Heat energy (originally from the sun) is the transfer or flow of energy between two systems, usually from a lower to a higher temperature. Heating and cooling allows matter to change states. But melting, boiling, freezing or evaporating, its atoms remain the same.

Heat is produced by molecules jiggling about. This causes friction. The more space between molecules, the more they're able to jiggle and the hotter a material gets.

Solids, liquids and gases have different energy levels, owing to how tightly or loosely their molecules are packed. Gases have the highest energy level of the three. Their molecules, being the most loosely organised, have the most jiggle room.



And something else: when you burn wood in a fireplace, its stored, potential energy is converted into three new forms: heat, sound and light (warmth, crackle and brightness). A small pile of ash

remains.

But *mass*, like energy, is conserved. Query: what happened to the rest of the mass? Answer: it went up in smoke. That is to say, it became carbon dioxide gas and water vapour. Only the bits that failed to burn remained as ash.

Behaviour like this caused the young Albert Einstein, mulling it over at the nuclear level, to reach an extraordinary and mind-boggling conclusion. If two *atomic nuclei* were fused together, they too would end up with less mass than they had when separate. So what, in this case, would have happened to the missing mass?

It must have become energy, Einstein concluded. *Matter and energy must be interchangeable - they must be different forms of the same thing.*

Einstein expressed it succinctly in his famous equation: $E=mc^2$. Energy equals mass, times the speed of light multiplied by itself. As the speed of light is 186,000 miles per second, the available energy in an atomic nucleus is something humongous – billions of times stronger than the chemical energy that breaks up molecules. Bang!



Radical ideas about matter were nothing new, of course. In the eighteenth century, Bishop Berkeley (mentioned earlier, as lampooned by Byron) had declared that matter wasn't *real*. He claimed material objects were creations of the eye and mind. (Plato and others had thought something similar.) 'To be is to be perceived,' said Berkeley. But the question then arose, if no one was looking at an object did it cease to exist? The philosopher-bishop dug himself out of that hole by saying God could see it – provoking further mockery in the limerick verses below (attributed to the theologian Ronald Knox).

There once was a man who said, 'God
Must find it exceedingly odd
If he finds that this tree
Continues to be
When there's no one about in the quad.'

'Dear Sir: Your astonishment's odd;
I am always about in the quad.
And that's why the tree
Will continue to be
Since observed by, Yours faithfully, God.'



Suddenly, matter was energy and vice versa. Atoms formed everything but they were always in flux. Every few years the stuff of human bodies was replaced. If energy was a construct, mightn't matter be as well, just as Bishop Berkeley had presumed?

The distinguished twentieth-century physicists, Niels Bohr and Werner Heisenberg, claimed that indeed matter wasn't real. Their eminent colleague Erwin Schrodinger claimed that indeed it was. Both views would become acceptable. Reality was experiencing its biggest shake-up since Isaac Newton laid down the laws of gravity and motion in the seventeenth century. Quantum physics had arrived.

To summarise:

- Energy is defined as the ability to do work. It has two categories: stored (potential) and moving (kinetic).
- Energy has several forms which can be *transferred* and/or *transformed*, one into another.
- Energy can be released from matter by breaking chemical bonds and by nuclear reactions.
- Energy and matter in the universe are conserved and interchangeable.

NB: If you've managed to get a grip on these three chapters – and it may take a bit of reviewing – you will know basically what matter is and how it's built up and energised to create every physical thing in the universe.

4

ANOTHER WORLD

'There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy.'

Shakespeare, *Hamlet*

Isaac Newton discovered that laws existed which governed the universe, and a force called gravity gave us a firm footing in it. Einstein saw things very differently. With imaginative, X-ray-like vision he perceived a universe beyond all sense perceptions. Its bizarre features would spark a rethink of the universe's nature that has continued ever since.

'Reality is merely an illusion, albeit a very persistent one,' Einstein once wryly observed. But unlike the reaction to Bishop Berkeley's rather similar notion, this time there was no lampooning. Einstein's insights and predictions have on the whole proved accurate.

Despite its revolutionary features, Einstein's world was generally an orderly one, with laws that guaranteed certain things always happened, given the same circumstances. But he was in for a shock. Pursuing the thread of his developing theories, he came upon a strange and wholly unexpected door. Naturally Einstein unlocked it. To his astonishment, he found he'd uncovered a madhouse: a topsy-turvy, seething micro-universe of mayhem, the wonderland of **quantum mechanics**. Einstein was incredulous. He couldn't – wouldn't – believe it. But today it is the norm.

Before taking a look, let's gaze for a moment at the great pillars of science Einstein's labours erected, and upon which all that followed was built.



A story goes that the French poet, Paul Valéry, meeting Einstein at a drinks party, asked the great man how he managed to keep track of his ideas. Did he carry a notebook, did he have a mnemonic system, did he scribble them hurriedly on his cuff – what was his method? Because, said Valéry, he faced that problem himself.

Einstein looked shyly down at his feet, then after a short pause answered, ‘I’ve only had two ideas.’

This modest reference was, first, to his idea that *photons* (light), which carry the electromagnetic force, aren’t waves but particles (for which he eventually received the Nobel Prize). The second idea appeared in a theoretical paper, ‘Special Relativity’, published in 1905. As the word ‘relativity’ implies, it contained the destabilising predictions that, together with its follow-up, ‘General Relativity’ (1915), would quake Newtonian terra firma. Both papers defied all common sense, and still do.

In brief: *special relativity* is about space and time, while *general relativity* is about gravity.

Einstein declared that time and motion are *relative*. Objects only move in relation to other objects. So, movement depends on viewpoint – where you’re placed or how you’re moving in relation to another object, or it to you. A visual thinker, Einstein used thought experiments to reach his unique conclusions. As a boy he’d imagined racing a light beam. If both were running at the same speed, then he wouldn’t know he was moving. If he was sitting on a train in the station and the train alongside moved forward, he would think it was his train that had moved.

But Einstein found one constant: the speed of light. At 186,000 miles per second, nothing could beat it. He further declared that mass and energy are interchangeable (as we have seen) and, of crucial significance, ditto space and time (see below). Then, having unified space and time, he redefined gravity, with a theory triggered by the thought that a man in free fall wouldn’t feel his own weight.



At the heart of **relativity theory** is time and space. Einstein declared the two were intertwined. The result, **spacetime**, has *four* dimensions: the usual three for space, plus one for time. Einstein said spacetime's fabric was like a smooth rubber sheet and the sun was an iron ball that, dropped on to the sheet, causes a trough around it (see Figure 3, p. 28). He said all objects distort spacetime in this way. The 'warping' or unevenness of spacetime's smooth fabric is what enables unfuelled objects to move in space. In other words, spacetime is distorted by the presence of matter, and the distortion allows matter to move.

Now, wherever there is matter there is gravity, as we know. Gravity pulled matter together in the first place. But **gravity**, said Einstein, is *not a physical force*, as Newton had assumed. Gravity is a result of warped spacetime. Newton had got that wrong.

The man he'd imagined in free fall would feel weightless because he *was* weightless. Gravity was acting on the space and time around him rather than on *him*. Gravity wasn't a force between objects, but the shape of spacetime changing.

Today spacetime remains, with modifications, a central plank of particle physics and cosmology, and general relativity is a cornerstone.

Even though quantum mechanics isn't understood, it works. And quantum and relativity theories work well together. Computers, lasers and nuclear reactors are examples of this.

But particle physics has failed in one crucially important aspect. It's been unable to include gravity in a QM 'theory of everything', which physicists aspire to.

Some hotly debated theories have sprouted to fill the gap.

Quantum field theory is accepted because it works. It claims the universe is made of particles and *fields*. But what exactly is a field?

Well, if someone is working in a field, it doesn't necessarily mean he's hoeing cotton. It could mean he's an historian or a scientist. That kind of field is an abstraction. The electromagnetic field, which carries electricity and light, was the first 'field' discovered in space, and it is physical. The level of reality of quantum fields is debatable. Some say quantum fields are a condition of space. Others claim that they *are* space. Space has a grainy structure, and particles are *vibrations* in it. In other words, fields and particles are the same thing, and the universe is one big quantum field of interactions. Reality isn't *things*; it's *interactions*. All is flux. There is no terra firma.

The recently confirmed Higgs field, containing the celebrated **Higgs boson particle**, gave quantum field theory a big boost. It's now accepted that all particles in the universe get mass from *interacting with Higgs particles in a Higgs field*. This is a big deal.

String theory, a variation of quantum field theory, posits the existence of infinitesimal strings of energy, smaller than quarks and shaped like ringlets, that can break open. The strings vibrate, rather like violin strings, with distinctive vibrations from the different particles. When they interact, the result is something like a musical universe playing its own highly peculiar symphony.

It sounds good, but string theory also claims that instead of Einstein's four spacetime dimensions, there are ten. The extra six are snugly curled up out of reach.

String theory and its competitors (below) depend on the existence of the so far undiscovered *graviton* particle.

image

not

available

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