RICHARD DAWKINS

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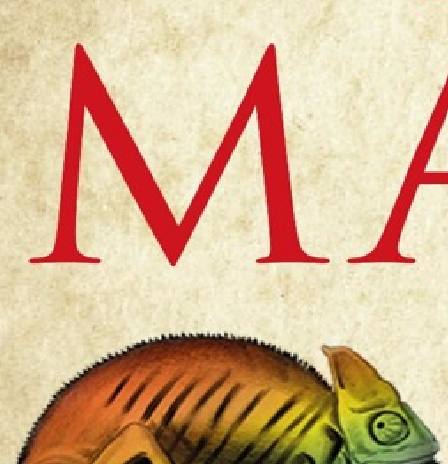
The Times

THE MAGIC OF REALITY



How we know what's really true

ILLUSTRATED BY DAVE McKEAN

About the Book

Magic takes many forms. The ancient Egyptians explained the night by suggesting that the goddess Nut swallowed the sun. The Vikings believed a rainbow was the gods' bridge to earth. These are magical, extraordinary tales. But there is another kind of magic, and it lies in the exhilaration of discovering the real answers to these questions. It is the magic of reality – science.

Packed with inspiring explanations of space, time and evolution, laced with humour and clever thought experiments, *The Magic of Reality* explores a stunningly wide range of natural phenomena. What is stuff made of? How old is the universe? What causes tsunamis? Who was the first man, or woman? This is a page-turning, inspirational detective story that not only mines all the sciences for its clues but primes the reader to think like a scientist too.

Richard Dawkins elucidates the wonders of the natural world to all ages with his inimitable clarity and exuberance in a text that will enlighten and inform for generations to come.

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RICHARD DAWKINS

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How we know what's really true

ILLUSTRATED BY DAVE McKEAN

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O, my beloved father

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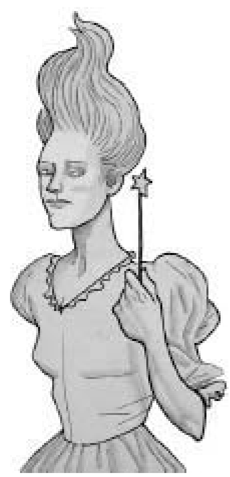
WHAT IS MAGIC?



REALITY IS EVERYTHING that exists. That sounds straightforward, doesn't it? Actually, it isn't. There are various problems. What about dinosaurs, which once existed but exist no longer? What about stars, which are so far away that, by the time their light reaches us and we can see them, they may have fizzled out?

We'll come to dinosaurs and stars in a moment. But in any case, how do we know things exist, even in the present? Well, our five senses – sight, smell, touch, hearing and taste – do a pretty good job of convincing us that many things are real: rocks and camels, newly mown grass and freshly ground coffee, sandpaper and velvet, waterfalls and doorbells, sugar and salt. But are we only going to call something 'real' if we can detect it directly with one of our five senses?

What about a distant galaxy, too far away to be seen with the naked eye? What about a bacterium, too small to be seen without a powerful microscope? Must we say that these do not exist because we can't see them? No. Obviously we can enhance our senses through the use of special instruments: telescopes for the galaxy, microscopes for bacteria. Because we understand telescopes and microscopes, and how they work, we can use them to extend the reach of our senses – in this case, the sense of sight – and what they enable us to see convinces us that galaxies and bacteria exist.

How about radio waves? Do they exist? Our eyes can't detect them, nor can our ears, but again special instruments – television sets, for example – convert them into signals that we can see and hear. So, although we can't see or hear radio waves, we know they are a part of reality.

As with telescopes and microscopes, we understand how radios and televisions work. So they help our senses to build a picture of what exists: the real world – reality. Radio telescopes (and X-ray telescopes) show us stars and galaxies through what seem like different eyes: another way to expand our view of reality.

Back to those dinosaurs. How do we know that they once roamed the Earth? We have never seen them or heard them or had to run away from them. Alas, we don’t have a time machine to show them to us directly. But here we have a different kind of aid to our senses: we have fossils, and we can see *them* with the naked eye. Fossils don’t run and jump but, because we understand how fossils are formed, they can tell us something of what happened millions of years ago. We understand how water, with minerals dissolved in it, seeps into corpses buried in layers of mud and rock. We understand how the minerals crystallize out of the water and replace the materials of the corpse, atom by atom, leaving some trace of the original animal’s form imprinted on the stone. So, although we can’t see dinosaurs directly with our senses, we can work out that they must have existed, using indirect evidence that still ultimately reaches us through our senses: we see and touch the stony traces of ancient life.

In a different sense, a telescope can work like a kind of time machine. What we see when we look at anything is actually light, and light takes time to travel. Even when you look at a friend’s face you are seeing them in the past, because the light from their face takes a tiny fraction of a second to travel to your eye. Sound travels much more slowly, which is why you see a firework burst in the sky noticeably earlier than you hear the bang. When you watch a man chopping down a tree in the distance, there is an odd delay in the sound of his axe hitting the tree.

Light travels so fast that we normally assume anything we see happens at the instant we see it. But stars are another matter. Even the sun is eight light-minutes away. If the sun blew up, this catastrophic event wouldn't become a part of our reality until eight minutes later. And that would be the end of us! As for the next nearest star, Proxima Centauri, if you look at it in 2012, what you are seeing is happening in 2008. Galaxies are huge collections of stars. We are in one galaxy called the Milky Way. When you look at the Milky Way's next-door neighbour, the Andromeda galaxy, your telescope is a time machine taking you back two and a half million years. There's a cluster of five galaxies called Stephan's Quintet, which we see through the Hubble telescope spectacularly colliding with each other. But we see them colliding 280 million years ago. If there are aliens in one of those colliding galaxies with a telescope powerful enough to see us, what they are seeing on Earth, at this very moment, here and now, is the early ancestors of the dinosaurs.

Are there really aliens in outer space? We've never seen or heard them. Are they a part of reality? Nobody knows; but we do know what kind of things could one day tell us if they are. If ever we got near to an alien, our sense organs could tell us about it. Perhaps somebody will one day invent a telescope powerful enough to detect life on other planets from here. Or perhaps our radio telescopes will pick up messages that could only have come from an alien intelligence. For reality doesn't just consist of the things we already know about: it also includes things that exist but that we don't know about yet and won't know about until some future time, perhaps when we have built better instruments to assist our five senses.

Atoms have always existed, but it was only rather recently that we became sure of their existence, and it is likely that our descendants will know about many more things that, for now, we do not. That is the wonder and the joy of science: it goes on and on uncovering new things. This doesn't mean we should believe just *anything* that anybody might dream up: there are a million things we can imagine but which are highly unlikely to be real – fairies and hobgoblins, leprechauns and hippogriffs. We should always be open-minded, but the only good reason to believe that something exists is if there is real evidence that it does.

Models: testing our imagination

There is a less familiar way in which a scientist can work out what is real when our five senses cannot detect it directly. This is through the use of a 'model' of what *might* be going on, which can then be tested. We imagine – you might say we guess – what might be there. That is called the model. We then work out (often by doing a mathematical calculation) what we ought to see, or hear, etc. (often with the help of measuring instruments) if the model were true. We then check whether that is what we actually do see. The model might literally be a replica made out of wood or plastic, or it might be a piece of mathematics on paper, or it might be a *simulation* in a computer. We look carefully at the model and *predict* what we ought to see or hear, etc. if the model were correct. Then we look to see whether the predictions are right or wrong. If they are right, this increases our confidence that the model really does represent reality; we then go on to devise further experiments, perhaps refining the model, to test the findings further and confirm them. If our predictions are wrong, we reject the model, or modify it and try again.

Here's an example. Nowadays, we know that genes – the units of heredity – are made of stuff called DNA. We know a great deal about DNA and how it works. But you can't see the details of what DNA looks like, even with a powerful microscope. Almost everything we know about DNA comes indirectly from dreaming up models and then testing them.

Actually, long before anyone had even heard of DNA, scientists already knew lots about genes from testing the predictions of models. Back in the nineteenth century, an Austrian monk called Gregor Mendel did experiments in his monastery garden, breeding peas in large quantities. He counted the numbers of plants that had flowers of various colours, or that had peas that were wrinkly or smooth, as the generations went by. Mendel never saw or touched a gene. All he saw were peas and flowers, and he could use his eyes to *count* different types. He invented a *model*, which involved what we would now call genes (though Mendel didn't call them that), and he calculated that, if his model were correct, in a particular breeding experiment there ought to be three times as many smooth peas as wrinkly ones. And that is what he found when he counted them. Leaving aside the details, the point is that Mendel's 'genes' were an invention of his imagination: he couldn't see them with his eyes, not even with a microscope. But he could see smooth and wrinkled peas, and by counting them he found indirect evidence that his *model* of heredity was a good representation of something in the real world. Later scientists used a modification of Mendel's method, working with other living things such as fruit flies instead of peas, to show that genes are strung out in a definite order, along threads called chromosomes (we humans have forty-six chromosomes, fruit flies have eight). It was even possible to work out, by testing models, the exact order in which genes were arranged along chromosomes. All this was done long before we knew that genes were made of DNA.

Nowadays we know this, and we know exactly how DNA works, thanks to James Watson and Francis Crick, plus a lot of other scientists who came after them. Watson and Crick could not see DNA with their own eyes. Once again, they made their discoveries by imagining models and testing them. In their case, they literally built metal and cardboard models of what DNA might look like, and they calculated what certain measurements ought to be if those models were correct. The predictions of one model, the so-called double helix model, exactly fitted the measurements made by Rosalind Franklin and Maurice Wilkins, using special instruments involving X-rays beamed into crystals of purified DNA. Watson and Crick also immediately realized that their model of the structure of DNA would produce exactly the kind of results seen by Gregor Mendel in his monastery garden.

We come to know what is real, then, in one of three ways. We can detect it directly, using our five senses; or indirectly, using our senses aided by special instruments such as telescopes and microscopes; or even more indirectly, by creating models of what *might* be real and then testing those models to see whether they successfully predict things that we can see (or hear, etc.), with or without the aid of instruments. Ultimately, it always comes back to our senses, one way or another.

Does this mean that reality only contains things that can be detected, directly or indirectly, by our senses and by the methods of science? What about things like jealousy and joy, happiness and love? Are these not also real?

Yes, they are real. But they depend for their existence on brains: human brains, certainly, and probably the brains of other advanced animal species, such as chimpanzees, dogs and whales, too. Rocks don’t feel joy or jealousy, and mountains do not love. These emotions are intensely real to those who experience them, but they didn’t exist before brains did. It is possible that emotions like these – and perhaps other emotions that we can’t begin to dream of – could exist on other planets, but only if those planets also contain brains – or something equivalent to brains: for who knows what weird thinking organs or feeling machines may lurk elsewhere in the universe?

Science and the supernatural: explanation and its enemy

So that is reality, and that is how we can know whether something is real or not. Each chapter of this book is going to be about one particular aspect of reality – the sun, for instance, or earthquakes, or rainbows, or the many different kinds of animals. I want now to turn to the other key word of my title: magic. Magic is a slippery word: it is commonly used in three different ways, and the first thing I must do is distinguish between them. I'll call the first one 'supernatural magic', the second one 'stage magic' and the third one (which is my favourite meaning, and the one I intend in my title) 'poetic magic'.

Supernatural magic is the kind of magic we find in myths and fairy tales. (In 'miracles', too, though I shall leave those to one side for now and return to them in the final chapter.) It's the magic of Aladdin's lamp, of wizards' spells, of the Brothers Grimm, of Hans Christian Andersen and of J. K. Rowling. It's the fictional magic of a witch casting a spell and turning a prince into a frog, or a fairy godmother changing a pumpkin into a gleaming coach. These are the stories we all remember with fondness from our childhood, and many of us still enjoy when served up in a traditional Christmas pantomime – but we all know this kind of magic is just fiction and does not happen in reality.

Stage magic, by contrast, really does happen, and it can be great fun. Or at least, *something* really happens, though it isn't what the audience thinks it is. A man on a stage (it usually is a man, for some reason) deceives us into thinking that something astonishing has happened (it may even *seem* supernatural) when what really happened was something quite different. Silk handkerchiefs cannot turn into rabbits, any more than frogs can turn into princes. What we have seen on the stage is only a trick. Our eyes have deceived us – or rather, the conjuror has gone to great pains to deceive our eyes, perhaps by cleverly using words to distract us from what he is really doing with his hands.

Some conjurors are honest and go out of their way to make sure their audiences know that they have simply performed a trick. I am thinking of people like James ‘The Amazing’ Randi, or Penn and Teller, or Derren Brown. Even though these admirable performers don’t usually tell the audience exactly *how* they did the trick – they could be thrown out of the Magic Circle (the conjurors’ club) if they did that – they do make sure the audience knows that there was no supernatural magic involved. Others don’t actively spell out that it was just a trick, but they don’t make exaggerated claims about what they have done either – they just leave the audience with the rather enjoyable sensation that something mysterious has happened, without actively lying about it. But unfortunately there are some conjurors who are deliberately dishonest, and who pretend they really do have ‘supernatural’ or ‘paranormal’ powers: perhaps they claim that they really can bend metal or stop clocks by the power of thought alone. Some of these dishonest fakes (‘charlatans’ is a good word for them) earn large fees from mining or oil companies by claiming that they can tell, using ‘psychic powers’, where would be a good place to drill. Other charlatans exploit people who are grieving, by claiming to be able to make contact with the dead. When this happens it is no longer just fun or entertainment, but preying on people’s gullibility and distress. To be fair, it may be that not all of these people are charlatans. Some of them may sincerely believe they are talking to the dead.

The third meaning of magic is the one I mean in my title: poetic magic. We are moved to tears by a beautiful piece of music and we describe the performance as ‘magical’. We gaze up at the stars on a dark night with no moon and no city lights and, breathless with joy, we say the sight is ‘pure magic’. We might use the same word to describe a gorgeous sunset, or an alpine landscape, or a rainbow against a dark sky. In this sense, 'magical' simply means deeply moving, exhilarating: something that gives us goose bumps, something that makes us feel more fully alive. What I hope to show you in this book is that reality – the facts of the real world as understood through the methods of science – is magical in this third sense, the poetic sense, the good to be alive sense.

Now I want to return to the idea of the supernatural and explain why it can never offer us a true explanation of the things we see in the world and universe around us. Indeed, to claim a supernatural explanation of something is not to explain it at all and, even worse, to rule out any possibility of its ever being explained. Why do I say that? Because anything 'supernatural' must by definition be beyond the reach of a natural explanation. It must be beyond the reach of science and the well-established, tried and tested scientific method that has been responsible for the huge advances in knowledge we have enjoyed over the last 400 years or so. To say that something happened supernaturally is not just to say 'We don't understand it' but to say 'We will never understand it, so don't even try.'

Science takes exactly the opposite approach. Science thrives on its inability – so far – to explain everything, and uses that as the spur to go on asking questions, creating possible models and testing them, so that we make our way, inch by inch, closer to the truth. If something were to happen that went against our current understanding of reality, scientists would see that as a challenge to our present model, requiring us to abandon or at least change it. It is through such adjustments and subsequent testing that we approach closer and closer to what is true.

What would you think of a detective who, baffled by a murder, was too lazy even to try to work at the problem and instead wrote the mystery off as 'supernatural'? The whole history of science shows us that things once thought to be the result of the supernatural – caused by gods (both happy and angry), demons, witches, spirits, curses and spells – actually do have natural explanations: explanations that we can understand and test and have confidence in. There is absolutely no reason to believe that those things for which science does not *yet* have natural explanations will turn out to be of supernatural origin, any more than volcanoes or earthquakes or diseases turn out to be caused by angry deities, as people once believed they were.

Of course, no one really believes that it would be possible to turn a frog into a prince (or was it a prince into a frog? I can never remember) or a pumpkin into a coach, but have you ever stopped to consider *why* such things would be impossible? There are various ways of explaining it. My favourite way is this.

Frogs and coaches are complicated things, with lots of parts that need to be put together in a special way, in a special pattern that can't just happen by accident (or by a wave of a wand). That's what 'complicated' means. It is very difficult to make a complicated thing like a frog or a coach. To make a coach you need to bring all the parts together in just the right way. You need the skills of a carpenter and other craftsmen. Coaches don't just happen by chance or by snapping your fingers and saying 'Abracadabra'. A coach has structure, complexity, working parts: wheels and axles, windows and doors, springs and padded seats. It would be relatively easy to turn something complicated like a coach into something simple – like ash, for instance: the fairy godmother's wand would just need a built-in blowtorch. It is easy to turn almost anything into ash. But no one could take a pile of ash – or a pumpkin – and turn it into a coach, because a coach is too complicated; and not just complicated, but complicated *in a useful direction*: in this case, useful for people to travel in.

Let's make it a bit easier for the fairy godmother by supposing that, instead of calling for a pumpkin, she had called for all the *parts* you need for assembling a coach, all jumbled together in a box: a sort of Ikea kit for a coach. The kit for making a coach consists of hundreds of planks of wood, panes of glass, rods and bars of iron, wads of padding and sheets of leather, along with nails, screws and pots of glue to hold things together. Now suppose that, instead of reading the instructions and joining the parts in an orderly sequence, she just put all the bits into a great big bag and shook them up. What are the chances that the parts would happen to stick themselves together in just the right way to assemble a working coach? The answer is – effectively zero. And a part of the reason for that is the massive number of *possible* ways in which you could combine the shuffled bits and pieces which would not result in a working coach – or a working *anything*.

If you take a load of parts and shake them around at random, they may just occasionally fall into a pattern that is useful, or that we otherwise recognize as somehow special. But the number of ways in which that can happen is tiny: very tiny indeed compared with the number of ways in which they will fall into a pattern that we don't recognize as anything more than a heap of junk. There are millions of ways of shuffling and reshuffling a heap of bits and pieces: millions of ways of transforming them into … another heap of bits and pieces. Every time you shuffle them, you get a unique heap of junk that has never been seen before – but only a tiny minority of those millions of possible heaps will do anything useful (such as taking you to the ball) or will be remarkable or memorable in any way.

Sometimes we can literally count the number of ways you can reshuffle a series of bits – as with a pack of cards, for instance, where the 'bits' are the individual cards.

Suppose the dealer shuffles the pack and deals them out to four players, so that they each have 13 cards. I pick up my hand and gasp in astonishment. I have a complete hand of *13 spades*! All the spades.

I am too startled to go on with the game, and I show my hand to the other three players, knowing they will be as amazed as I am.

But then, one by one, each of the other players lays his cards on the table, and the gasps of astonishment grow with each hand. Every one of them has a ‘perfect’ hand: one has 13 hearts, another has 13 diamonds, and the last one has 13 clubs.

Would this be supernatural magic? We might be tempted to think so. Mathematicians can calculate the chance of such a remarkable deal happening purely by chance. It turns out to be almost impossibly small: 1 in 53,644,737,765,488,792, 839,237,440,000. If you sat down and played cards for a trillion years, you might on one occasion get a perfect deal like that. But – and here’s the thing – this deal is no more unlikely than *every other deal of cards that has ever happened!* The chance of *any* particular deal of 52 cards is 1 in 53,644,737,765,488,792, 839,237,440,000 because that is the total number of all possible deals. It is just that we don’t notice any particular pattern in the vast majority of deals that are made, so they don’t strike us as anything out of the ordinary. We only notice the deals that happen to stand out in some way.

There are billions of things you could turn a prince into, if you were brutal enough to rearrange his bits into billions of combinations at random. But most of those combinations would look like a mess – like all those billions of meaningless, random hands of cards that have been dealt. Only a tiny minority of those possible combinations of randomly shuffled prince-bits would be recognizable or good for anything at all, let alone a frog.

Princes don’t turn into frogs, and pumpkins don’t turn into coaches, because frogs and coaches are complicated things whose bits could have been combined into an almost infinite number of heaps of junk. And yet we know, as a fact, that every living thing – every human, every crocodile, every blackbird, every tree and even every Brussels sprout – has evolved from other, originally simpler forms. So isn't *that* just a process of luck, or a kind of magic? No! Absolutely not! This is a very common misunderstanding, so I want to explain right now why what we see in real life is not the result of chance or luck or anything remotely 'magical' at all (except, of course, in the strictly poetic sense of something that fills us with awe and delight).

The slow magic of evolution

To turn one complex organism into another complex organism in a single step – as in a fairy tale – would indeed be beyond the realms of realistic possibility. And yet complex organisms *do* exist. So how did they arise? How, in reality, did complicated things like frogs and lions, baboons and banyan trees, princes and pumpkins, you and me come into existence?

For most of history that was a baffling question, which no one could answer properly. People therefore invented stories to try to explain it. But then the question was answered – and answered brilliantly – in the nineteenth century, by one of the greatest scientists who ever lived, Charles Darwin. I'll use the rest of this chapter to explain his answer, briefly, and in different words from Darwin's own.

The answer is that complex organisms – like humans, crocodiles and Brussels sprouts – did not come about suddenly, in one fell swoop, but gradually, step by tiny step, so that what was there after each step was only a little bit different from what was already there before. Imagine you wanted to create a frog with long legs. You could give yourself a good start by beginning with something that was already a bit like what you wanted to achieve: a frog with short legs, say. You would look over your short-legged frogs and measure their legs. You'd pick a few males and a few females that had slightly longer legs than most, and you'd let them mate together, while preventing their shorter-legged friends from mating at all.

The longer-legged males and females would make tadpoles together, and these would eventually grow legs and become frogs. Then you'd measure this new generation of frogs, and once again pick out those males and females that had longer-than-average legs, and put them together to mate.

After doing this for about 10 generations, you might start to notice something interesting. The average leg length of your population of frogs would now be noticeably longer than the average leg length of the starting population. You might even find that *all* the frogs of the 10th generation had longer legs than any of the frogs of the first generation. Or 10 generations might not be enough to achieve this: you might need to go on for 20 generations or even more. But eventually you could proudly say, 'I have made a new kind of frog with longer legs than the old type.'

No wand was needed. No magic of any kind was required. What we have here is the process called *selective breeding*. It makes use of the fact that frogs vary among themselves and those variations tend to be inherited – that is, passed on from parent to child via the genes. Simply by choosing which frogs breed and which do not, we can make a new kind of frog.

Simple, isn't it?

But just making legs longer is not very impressive. After all, we started with frogs – they were just short-legged frogs. Suppose you started, not with a shorter-legged form of frog, but with something that wasn't a frog at all, say something more like a newt. Newts have very short legs compared with frogs' legs (compared with frogs' *hind* legs, at least), and they use them not for jumping but for walking. Newts also have long tails, whereas frogs don't have tails at all, and newts are altogether longer and narrower than most frogs. But you can see that, given enough thousands of generations, you could change a population of newts into a population of frogs, simply by patiently choosing, in each of those millions of generations, male and female newts that were slightly more frog-like and letting them mate together, while preventing their less frog-like friends from doing so. At no stage during the process would you see any dramatic change. Every generation would look pretty much like the previous generation, but nevertheless, once enough generations had gone by, you'd start to notice that the average tail length was slightly shorter and the average pair of hind legs was slightly longer. After a very large number of generations, the longer-legged, shorter-tailed individuals might find it easier to start using their long legs for hopping instead of crawling. And so on.

Of course, in the scenario I have just described, we are imagining ourselves as breeders, picking out those males and females that we want to mate together in order to achieve an end result that we have chosen. Farmers have been applying this technique for thousands of years, to produce cattle and crops that have higher yields or are more resistant to disease, and so on. Darwin was the first person to understand that it works *even when there is no breeder to do the choosing*. Darwin saw that the whole thing would happen *naturally*, as a matter of course, for the simple reason that some individuals survive long enough to breed and others don't; and those that survive do so because they are better equipped than others. So the survivors' children inherit the genes that helped their parents to survive. Whether it's newts or frogs, hedgehogs or dandelions, there will always be some individuals that are better at surviving than others. If long legs happen to be helpful (for frogs or grasshoppers jumping out of danger, say, or for cheetahs hunting gazelles or gazelles fleeing from cheetahs), the individuals with longer legs will be less likely to die. They will be more likely to live long enough to reproduce. Also, more of the individuals available for mating with will have long legs. So in every generation there will be a greater chance of the genes for longer legs being passed into the next generation. Over time we will find that more and more of the individuals within that population have the genes for longer legs. So the effect will be exactly the same as if an intelligent designer, such as a human breeder, had chosen long-legged individuals for breeding – except that *no such designer is required*: it all happens naturally, all by itself, as the automatic consequence of which individuals survive long enough to reproduce, and which don't. For this reason, the process is called *natural selection*.

Given enough generations, ancestors that look like newts can change into descendants that look like frogs. Given even more generations, ancestors that look like fish can change into descendants that look like monkeys. Given yet more generations, ancestors that look like bacteria can change into descendants that look like humans. And this is exactly what happened. This is the kind of thing that happened in the history of every animal and plant that has ever lived. The number of generations required is larger than you or I can possibly imagine, but the world is thousands of millions of years old, and we know from fossils that life got started more than three and a half billion years ago, so there has been plenty of time for evolution to happen.

This is Darwin's great idea, and it is called Evolution by Natural Selection. It is one of the most important ideas ever to occur to a human mind. It explains everything we know about life on Earth. Because it is so important, I'll come back to it in later chapters. For now, it is enough to understand that evolution is very slow and gradual. In fact, it is the gradualness of evolution that allows it to make complicated things like frogs and princes. The magical changing of a frog into a prince would be not gradual but sudden, and this is what rules such things out of the world of reality. Evolution is a real explanation, which really works, and has real evidence to demonstrate the truth of it; anything that suggests that complicated life forms appeared suddenly, in one go (rather than evolving gradually step by step), is just a lazy story – no better than the fictional magic of a fairy godmother's wand.

As for pumpkins turning into coaches, magic spells are just as certainly ruled out for them as they are for frogs and princes. Coaches don't evolve – or at least, not naturally, in the same way that frogs and princes do. But coaches – along with airliners and pickaxes, computers and flint arrowheads – are made by humans who *did* evolve. Human brains and human hands evolved by natural selection, just as surely as newts' tails and frogs' legs did. And human brains, once they had evolved, were able to design and create coaches and cars, scissors and symphonies, washing machines and watches. Once again, no magic. Once again, no trickery. Once again, everything beautifully and simply explained.

In the rest of this book I want to show you that the real world, as understood scientifically, has magic of its own – the kind I call poetic magic: an inspiring beauty which is all the more magical because it is real and because we can understand how it works. Next to the true beauty and magic of the real world, supernatural spells and stage tricks seem cheap and tawdry by comparison. The magic of reality is neither supernatural nor a trick, but – quite simply – wonderful. Wonderful, and real. Wonderful *because* real.