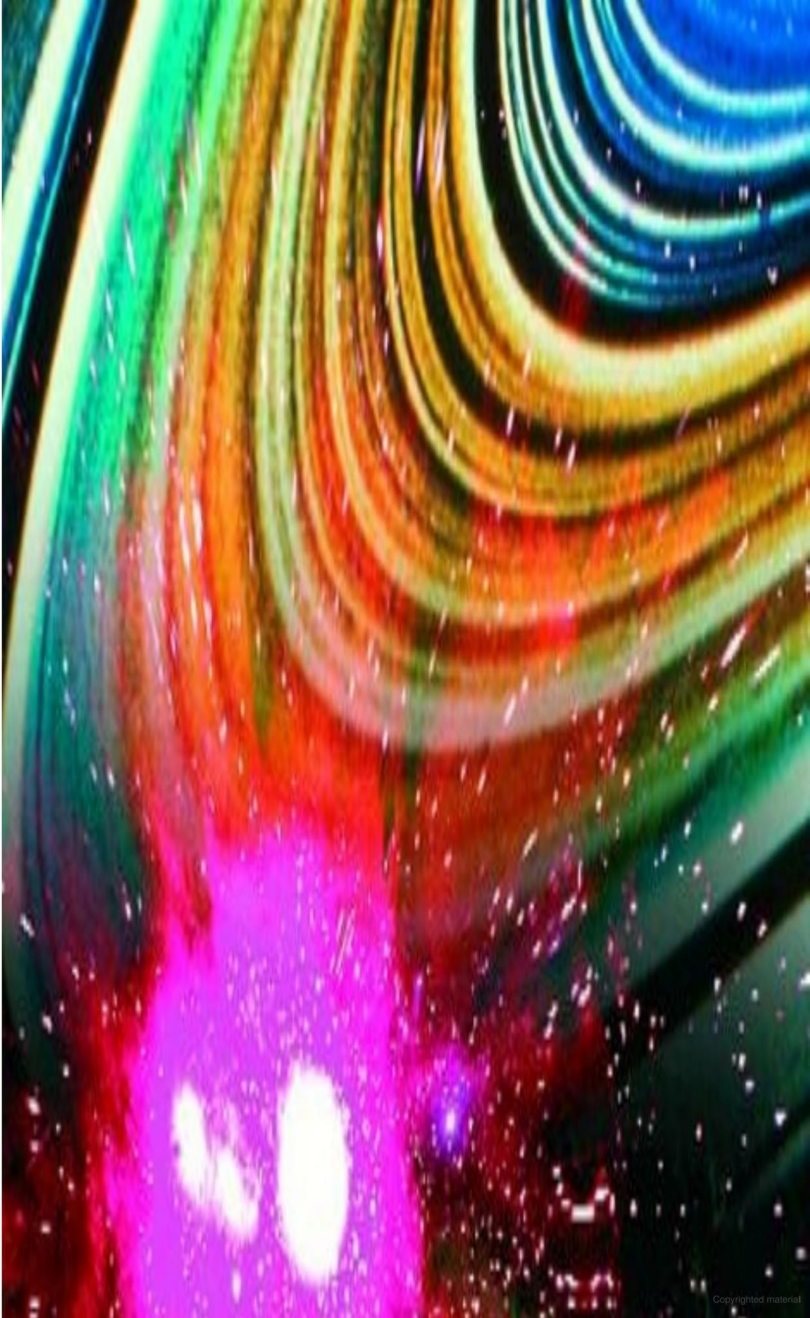

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# THE FABER BOOK OF Science

edited by

JOHN CAREY

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# Introduction

The aim of this book is to make science intelligible to non-scientists. Of course, like any anthology, it is meant to be entertaining, intriguing, lendable-to-friends and good-to-read as well, and the first question I asked about any piece I thought of including was, Is this so well written that I want to read it twice? If the answer was no, it was instantly scrapped. But alongside this question I asked, Does this supply, as it goes along, the scientific knowledge you need to understand it? Will it be clear to someone who is not mathematical, and has no extensive scientific education? Even if it was admirable in other ways, failure to qualify on these counts landed it on the reject pile.

Scientists themselves are not always good at judging intelligibility – and why should they be? They are specialists, paid to communicate with fellow specialists. Of course, they have to communicate, too, with industry, the government, grant-giving bodies and other institutions. But they can often assume a level of expertise in these negotiations which is well above that of the general public. Over the last five years I have read many books and articles by scientists, ostensibly for a popular readership, which start out intelligibly and fairly soon hit a quagmire of equations or a thicket of fuse-blowing technicalities, from which no non-scientist could emerge intact. *Relativity: The Special and General Theory. A Popular Exposition,* by Albert Einstein, Ph.D. (1920) is only a particularly distinguished example of a class of 'popular expositions', still being published, that could not conceivably be understood by more than a tiny fraction of any populace.

Fortunately for this anthology, however, popular science has improved immensely in the later twentieth century. Writers like Isaac Asimov, Arthur C. Clarke, Martin Gardner, Freeman Dyson, Carl Sagan, Richard Feynman, Stephen Jay Gould, Peter Medawar, Stephen Hawking, Lewis Wolpert and Richard Dawkins have transformed the genre, combining expert knowledge with an urge to be understood, and bridging the intelligibility gap to delight and instruct huge readerships. In the process, they have created a new kind of late twentieth-century literature, which demands to be recognized as a separate genre, distinct from the old literary forms, and conveying pleasures and triumphs quite distinct from theirs.

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True, these writers had predecessors in the nineteenth century – T. H. Huxley, for example, or Charles Darwin himself, who also strove to reach the general reading public. But in the mid-nineteenth century the general reading public was a much smaller and more select thing than it is now. The challenge for a late twentieth-century writer of popular science is different and greater. The books that succeed represent achievements of a remarkable and unprecedented kind. Nor is it clear on what grounds they can be reckoned inferior to novels, poems and other representatives of the older genres. In what respect, for example, is a masterpiece like Richard Dawkins's *The Blind Watchmaker* imaginatively inferior to a distinguished work of fiction such as Martin Amis's *Einstein's Monsters* (or the hundreds of lesser novels that jam the publishers' lists each year)? Both are clearly the products of brilliant minds; both are highly imaginative; and Amis is more excited by scientific ideas than most contemporary writers. Nevertheless, the essential distinction between them seems to be that between knowledge and ignorance. From the viewpoint of late twentieth-century thought, Dawkins's book represents the instructed and Amis's the uninstructed imagination.

Because I wanted the pieces I included to be seriously informative as well as enjoyable, I decided not to allow in science fiction (which would, in any case, need an anthology of its own), or those plentiful anecdotes about scientists' private lives which show how droll or winning they were despite their erudition. The misty precursors of true science – alchemy, astrology – have also been left out, partly because they can now be classified as history not science, and partly because they tend to encourage in the reader an amused and superior response which is not the reaction I am looking for.

For similar reasons I decided, after some hesitation, not to include ancient science (Aristotle, Pliny, etc.). It is true, of course, that this sometimes foreshadows modern science. But even when it does it is often forbiddingly technical, in a way that no amount of jazzing-up in translation can overcome. After a good deal of searching, I concluded that there were virtually no examples of ancient science that would have anything more than curiosity value – if that – for a general reader today. So my anthology starts with the Renaissance, at a point where two sciences, anatomy and astronomy, take decisive steps towards the modern age, and find exponents who can still be read with pleasure.

A final kind of writing I decided (rather quickly) to exclude was the large body of opinionativeness that has gathered around such questions as whether science is a Good or a Bad

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Thing, and whether we would be better off if we did not know the earth went round the sun. Ignorance and prejudice seem to be the most prolific contributors to this branch of controversy, and I am not anxious to give either house-room.

In the main, then, I have tried to stick to serious science, though serious science softened up for general consumption. Scientists will object quite rightly that I have included technology as well as science. The pieces on the Wright brothers' aeroplane or on Daguerre and the first photograph, for example, would not figure in a strictly scientific anthology. But I included them and others because, for the general reader, science and technology are intimately connected – as, indeed, they are for scientists. Photography and manned flight both became possible because of scientific perceptions, and technology has advanced scientific discovery from the time of Galileo's telescope.

Choosing the passages to include was one thing: arranging them, another. Should I separate out the various sciences – all the biology pieces in one section; all the chemistry in another? Or would a roughly chronological arrangement be better? I decided it would, because jumping from science to science with each item makes for a livelier read, and the chronological framework turns the book into a story – a way of taking in the development of science over the last five centuries. Some of this story-telling is carried on in the introductions to each extract, and sometimes – as, for example, in the sections on Relativity and the Uncertainty Principle – I have drawn together material from several sources, including poets and novelists, to show how a particular scientific discovery did, or did not, enter the bloodstream of the culture.

Broadly speaking science-writing tends towards one of two modes, the mind-stretching and the explanatory. In practice, of course, any particular piece of science-writing will combine the two in various proportions. Still, they seem to be the extremes between which science-writing happens. The mind-stretching, also called the gee-whizz mode, aims to arouse wonder, and corresponds to the Sublime in traditional literary categories. When scientists tell us that if we could place in a row all the capillaries in a single human body they would reach across the Atlantic, or that the average man has 25 billion red blood corpuscles, or that the number of nerve cells in the cerebral cortex of the brain is twice the population of the globe, these are contributions to the mind-stretching mode – which does not mean, of course, that they are not serious and profound in their implications as well. A similarly amazing example, and less flattering to our self-esteem, is the proposition (from an essay

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by George Wald) that though a planet of the earth's size and temperature is a comparatively rare event in the universe, it is estimated that at least 100,000 planets like the earth exist in our galaxy alone, and since some 100 million galaxies lie within the range of our most powerful telescopes, it follows that throughout observable space we can count on the existence of at least 10 million million planets more or less like ours.

As readers will find, I have included some examples of this mode in my anthology, because the peculiar thrill and spiritual charge of science would not be fairly represented without it. But my preference has been, and is, for the other mode, the explanatory. What I most value in-science-writing is the feeling of enlightenment that comes with a piece of evidence being correctly interpreted, or a problem being ingeniously solved, or a scientific principle being exposed and clarified. There are many instances of these three processes in the anthology, but if I had to choose one favourite example of each they would be from Galileo, Darwin and Haldane respectively.

When Galileo looked at the moon through his telescope, he and everyone else thought it was a perfect sphere. He was astonished, he tells us, to see bright points within its darkened part, which gradually increased in size and brightness till they joined up with its bright part. It occurred to him that they were just like mountain tops on earth, which are touched by the sun's morning rays while the lower ground is still in shadow. So he deduced correctly that the moon's surface was not smooth after all, but mountainous. To follow Galileo as he explains his observations step by step is to share an experience of scientific enlightenment that fiction and poetry, for all their powers, cannot give, since they can never be so authentically engaged with actuality and discovery.

Darwin supplies a beautiful example of the second process, the ingenious solution of a problem, when he is faced with the need to explain how species of freshwater plants could spread to remote oceanic islands without being separately created by God. It occurs to him that the seeds might be carried on the muddy feet of wading birds that frequent the edges of ponds. But that raises the question of whether pond mud contains seeds in sufficient quantities. So he takes three tablespoonfuls of mud from the edge of his pond in February – enough to fill a breakfast cup – and keeps it covered in his study for six months, pulling up and counting each plant as it grows. Five hundred and thirty-seven plants grow, of many different species, so that Darwin is able to conclude that it would be an 'inexplicable circumstance' if wading birds did not transport the seeds of freshwater plants, as he had suspected. Once again, fiction

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could not compete with the impact of this, since the force of Darwin's account depends precisely on its not being fiction but fact.

J. B. S. Haldane's famous essay 'On Being the Right Size' superbly exemplifies the third process – the exposition of a scientific principle. Restricting his mathematics to simple arithmetic, and keeping in mind the need for powerful, graphic examples, Haldane is able to demonstrate, unforgettably, by the end of his second paragraph, that the 60-foot-high Giants Pope and Pagan in Bunyan's *Pilgrim's Progress* could never have existed, because they would have broken their thighs every time they walked. The example is, of course, purposefully chosen, for out goes, with Bunyan, the whole world of (as Haldane saw it) religious mumbo-jumbo that Bunyan stood for, and the light of pure reason comes flooding in instead.

But if the explanatory mode is science-writing's breath of life – its armoury, palette and climate – the problem for science-writers is how to explain. How can science be made intelligible to non-scientists? The least hopeful answer is that it cannot. Giving an inkling of what modern science means to readers who cannot manage higher mathematics is, Richard Feynman has proposed, like explaining music to the deaf. This would be a desolating conclusion if Feynman were not himself among the most brilliant of explainers. His success depends upon his genius for making his material human. He saturates his writing with his individual style and personality. But, more than that, he freely imports a kind of animism into his experimental accounts – discussing, for example, how an individual photon 'makes up its mind' which of a number of possible paths to follow.

Ruskin uses animism, too, when – in his masterly tribute to rust – he tells his readers that iron 'breathes', and 'takes oxygen from the atmosphere as eagerly as we do'. Miroslav Holub is animistic when (in perhaps the most mind-expanding piece in the whole anthology) he imagines the adrenalin and the stress hormones in the spilt blood of a dead muskrat still sending out their alarms, and the white blood cells still busily trying to perform their accustomed tasks, bewildered by the unusual temperature outside the muskrat's body. In fact, Feynman-Ruskin-Holub-type animism is a persistent ally in the popular science-writer's struggle to engage the reader's understanding.

To a scientist, this might seem ridiculous. Lewis Carroll rubbished the whole idea in *The Dynamics of a Particle:*

It was a lovely Autumn evening, and the glorious effects of

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> chromatic aberration were beginning to show themselves in the atmosphere as the earth revolved away from the great western luminary, when two lines might have been observed wending their weary way across a plane superficies. The elder of the two had by long practice acquired the art, so painful to young and impulsive loci, of lying evenly between his extreme points; but the younger, in her girlish impetuosity, was ever longing to diverge and become a hyperbola or some such romantic and boundless curve ...

However, it is not clear that animism is as daft as Carroll makes it appear. All science is inevitably drenched in our human presumptions, designs and conceptions. We cannot get outside the human shapes of our brains. Our observation inevitably alters what it observes. This perception is usually associated with Heisenberg. But it was already evident to Francis Bacon at the start of the seventeenth century, who saw that perfect, pure objective science was impossible, not only because we are forced to use language, or some kind of numerical notation, which does not 'naturally' belong to the objects we name or number, but also because we seek patterns, shapes and symmetries in nature which correspond to our own preconceptions, not to anything that is 'really' there. From this viewpoint, to say that iron 'breathes' is no more absurd than to say that it is called 'iron', or that its chemical symbol is Fe. In each case, we add something human to its remote, alien, unknowable nature – a nature that has nothing to do with human thought, and is therefore altered the instant we think about it.

Whatever reservations the reader may have about this line of argument, it remains true that animism is extraordinarily useful to science-writers, as many pieces in this book testify. To preserve a personal element I have also tried, as often as I could, to present scientists talking about themselves at the moment of discovery. Nothing can match the immediacy of such accounts. Francis Jehl's description of the feverish months of trial and error that preceded the development of the world's first electric light bulb in Edison's laboratory, or Ronald Ross's memory of the sweltering afternoon in Secunderabad when he saw, through his microscope, the secret of malaria, or William Beebe exclaiming at the astonishing blueness of the sea 700 feet beneath the ocean, so intense that it drives even the thought of any other colour out of his head – if I could have found enough of them, I should have been tempted to make my whole anthology out of pieces like this.

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Given the boundless human implications of science, it seems strange that poets have not used it more. One of my disappointments in editing this anthology was to find so little poetry – or so little that was not embarrassingly bad. Lifting the embargo on ancient science would have helped a bit, because I could have included some Lucretius – but it would have been too high a price. Among English poets, even Shelley, who knew more about science than most, does not really write scientific poetry. To treat 'The Cloud', say, as a poem about meteorology (though it is that) would be to ignore most of its meaning. Generally speaking, science has had a bad effect on poets, inciting them to bombast (of the 'O thou terrestrial ball' variety) or to drivelling regrets that science has banished 'faery lore'.

Science's dominant position in contemporary culture might surely have been expected to breed some modern scientific poets. Yet most poets remain science-blind. There are a few distinguished exceptions, as the reader will find: John Updike, Lavinia Greenlaw, John Frederick Nims. But neglect is the norm. Why?

Perhaps because it is assumed that the poetic imagination is superior to the scientific, so poets simply need not bother with science. Certainly this used to be a favourite idea. 'I believe the souls of 500 Sir Isaac Newtons would go to the making up of a Shakespeare or a Milton,' pronounced Samuel Taylor Coleridge. Convictions of this kind still linger, especially among those who know nothing about Sir Isaac Newton. Yet Coleridge's credo does not, when you inspect it, mean much. Presumably he relates soul-size to imaginative power – and obviously poets do use their imagination differently from scientists. But there seem no grounds for deciding they use it better – or worse.

The difference can be seen right at the start of the modern scientific era if we glance, for example, at the way Shakespeare and Bacon write about clocks. For Shakespeare a clock is something that tells the time. 'When I do count the clock that tells the time,' one of his sonnets starts. But for Bacon a clock is a machine which, because he understands it scientifically, he can put to various uses. Thinking about weight and gravitation, he wondered if the weight of an object would increase and decrease according to whether it was nearer to or further from the centre of the earth. Obviously you cannot discover this by weighing the object at various heights, because the weights themselves will also have got heavier or lighter, like the object. What you do, Bacon decides, is take two clocks, one worked by weights, the other by a spring. You adjust them so they are running at the same speed, then you take them up a mountain and down a mine. Up the mountain the clock with weights will

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go slower, because they have become lighter. Down the mine it will go faster.

He was almost right. The clock with weights would go slower up the mountain. But since the earth's weight is not concentrated at its centre, the clock going down the mine would leave progressively more of the earth's mass above it, so it would go slower too. The point, though, is not Bacon's Tightness or wrongness, but the way he thinks about clocks compared to Shakespeare. For Shakespeare the idea of a clock has shrunk to something that tells the time. For Bacon, the clock is a machine, which can be engineered in various ways, and which has an experimental potential independent of the time-telling role ordinary language has allocated to it. It seems rather unfair to call Bacon less imaginative than Shakespeare in this instance. The poet remains satisfied with the conventional attributes of clocks, whereas the scientist's exploratory mind takes him to a wholly new function for a clock, which reveals something unexpected about the universe.

Of course this example is grossly slanted in Bacon's favour, and it would be ridiculous to disparage Shakespeare on the strength of it. Shakespeare's sonnet is no less a great poem because it is uninterested in gravitation. I have risked the comparison with Bacon because it shows us already, at the start of the seventeenth century, a scientist needing to rid himself of language's normal constraints (the usual functions language assigns to 'clock'), in order to think. From this historical moment on, scientists increasingly found that they had to develop their own special language, esoteric and forbidding to outsiders, but valuable to scientists because of its freedom from the vast cloud of associations, nuances and ambiguities that ordinary language carries along with it, and on which poets depend.

To poets, the new technical language seemed a sterile sea of jargon, in which the imagination would freeze and drown. John Donne was the first and last English poet *not* to feel like this about scientific language. He was lucky, being born at just the right time (1572), after the beginning of modern science but before its specialized technical vocabularies had really taken off. So for him, scientific language could still be warm, mysterious and sonorous, like poetry. He could think of love, and the scientific methods used for establishing latitude and longitude, as perfectly compatible and mutually enriching subjects:

> How great love is, presence best trial makes
> But absence tries how long this love will be;

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To take a latitude
Sun, or stars, are fitliest viewed
At their brightest, but to conclude
Of longitudes, what other way have we,
But to mark when, and where, the dark eclipses be?

Not much more than fifty years later, Milton took an altogether different and alienated view of scientists and scientific language, deriding astronomers who:

Gird the sphere
With centric and eccentric scribbled o'er,
Cycle and epicycle, orb in orb.

Comparing the two examples we can see science, in the space of a half-century (the same half-century that saw the foundation of the Royal Society), beginning to become a hated alternative to poetry, barbaric, ugly, offensive to cultured ears. By the early twentieth century the process had developed so far that the Spanish philosopher José Ortega y Gasset, in *The Revolt of the Masses,* could select science (along with democracy) as a key cause of modern 'primitivism and barbarism'. He regretted that 'while there are more scientists than ever before, there are far fewer cultured men.'

Wordsworth, roughly halfway between Donne and us, prophesied that things would not turn out like this. He believed that science should and would become a subject for poetry. In 1800 he wrote:

> If the labours of men of science should ever create any material revolution, direct or indirect in our condition, and in the impressions which we habitually receive, the poet will sleep then no more than at present, he will be ready to follow the steps of the man of science, not only in those general indirect effects, but he will be at his side, carrying sensation into the midst of the objects of the science itself. The remotest discoveries of the chemist, the botanist, or mineralogist, will be as proper objects of the poet's art as any upon which it can be employed.

But Wordsworth was wrong. This has not happened; or not yet. Perhaps, as more scientists follow the trend of the writers I have mentioned, and make science available to general readers, it will permeate the culture and Wordsworth's prophecy will come true. As things are, however, modern poets avoid science, and, it seems, because they feel inferior to it, not (like

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Coleridge) superior. W. H. Auden expresses the general loss of confidence: 'When I find myself in the company of scientists, I feel like a shabby curate who has strayed by mistake into a drawing room full of dukes.'

Resistance to science among what Ortega y Gasset calls 'cultured men' has sometimes been strengthened by the objection that science is godless and amoral. Both charges need some qualification. It is perfectly possible for a scientist to believe in God, and even to find scientific evidence for God's existence. To sceptics this might suggest a rather nutty combination of laboratory-bore and Jesus-freak. But when a scientist of James Clerk Maxwell's eminence uses molecular structure as an argument for the existence of God, few will feel qualified to laugh. Of course, atheistical scientists are plentiful too. The zoologist Richard Dawkins has voiced the suspicion that all religions are self-perpetuating mental viruses. But since everything science discovers can, by sufficiently resolute believers, be claimed as religious knowledge, because it must be part of God's design, science cannot be regarded as inherently anti-religious.

On the contrary, its aims seem identical with those of theology, in that they both seek to discover the truth. Science seeks the truth about the physical universe; theology, about God. But these are not essentially distinct objectives, for theologians (or at any rate Christian theologians) believe God created the universe, so may be contacted through it. Admittedly, many scientists insist that science and religion are irreconcilable. The neuropsychologist Richard Gregory has declared: 'The attitudes of science and religion are essentially different, and opposed, as science questions everything rather than accepts traditional beliefs.' This does less than justice to religion's capacity for change. The whole Reformation movement in Europe, for example, was about not accepting traditional beliefs. It might be objected that science depends on evidence, while religion depends on revealed truth, and that this constitutes an insuperable difference. But for the religious, revealed truth is evidence. Theology might, without any paradox, be regarded as a science, committed to persistently questioning and reinterpreting the available evidence about God. True, by calling itself 'theology' it appears to take it for granted that God (*theos*) exists, which, scientifically speaking, is rather a careless usage. However, there is no reason why theological research should not lead the researcher to atheism, and no doubt it often has, just as (as we have seen) scientific research has led some researchers to God.

The real antithesis of science seems to be not theology but

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politics. Whereas science is a sphere of knowledge, politics is a sphere of opinion. Politics is constructed out of preferences, which it strives to elevate, by the mere multiplication of words, to the status of truths. Politics depends on personalities and rhetoric; social class, race and nationality are elemental to it. All of these are irrelevant to science. Further, politics relies, for its very existence, upon conflict. It presupposes an enemy. It is essentially oppositional, built on warring prejudices. If this oppositional structure were to collapse, politics could not survive. There could be no politics in a world of total consensus. Science, by contrast, is a co-operative not an oppositional venture. Of course, the history of science resounds with ferocious argument and the elaboration and destruction of rival theories. But when consensus is reached science does not collapse, it advances. Another crucial difference is that politics aims to coerce people. It is concerned with the exercise of power. Science has no such designs. It seeks knowledge. The consequence of this difference is that politics can and frequently does use violence (war, genocide, terrorism) to secure its ends. Science cannot. It would be ludicrous to go to war to decide upon the truth or otherwise of the second law of thermodynamics.

Needless to say, the ideal state I have described, in which science is free from and antithetical to politics, is not one that survives in the real world, where politics invades and contaminates science as it does everything else. But the warlike and destructive uses to which science has been put have nothing essentially to do with science: they are the responsibility of politics. Science's apolitical nature is worth stressing, because it helps us to defuse the charge that it is amoral. It allows us to see science's amorality not as a defect but as a condition of its strength and purity. Politics, of course, is inseparable from morality. It battens on morality, or on moralizing, like a tapeworm on the gut. Consequently science could not free itself from politics except by being amoral.

Approaches to life that are, in moral terms, cold, clinical and inhuman, are sometimes labelled 'scientific', but this is a misunderstanding, arising from the simple-minded transference of scientific method to moral attitudes. Science endorses no such transference, and no moral attitudes, cold or otherwise. In different minds, the same set of scientific propositions can prompt quite contrary moral responses. Darwin's theory of evolution, relating humans to apes, seemed – and seems – degrading to many humans. But Bruce Frederick Cummings accepts it with gusto:

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> As for me, I am proud of my close kinship with other animals. I take a jealous pride in my Simian ancestry. I like to think that I was once a magnificent hairy fellow living in the trees and that my frame has come down through geological time via sea-jelly and worms and Amphioxus, Fish, Dinosaurs, and Apes. Who would exchange these for the pallid couple in the Garden of Eden?

Scientists themselves may have moral or immoral reasons for pursuing their research. But these leave no mark on their findings, which are right or wrong, to whatever degree, irrespective of their discoverer's motives. David Bodanis may be right to trace a link between Pasteur's loathing of mass humanity and his connection of disease with bacteria. The scientific credentials of the connection are, however, neither strengthened nor weakened by Pasteur's misanthropy.

The last few paragraphs may prompt readers to ask why they should bother to know about science if it cannot help to resolve moral or religious questions. The best answer is that science is, simply, what is known, and the only alternative to it is ignorance. Coleridge (whatever his opinion of Sir Isaac Newton's soul) saw this clearly:

> The first man of science was he who looked into a thing, not to learn whether it could furnish him with food, or shelter, or weapons, or tools, or ornaments, or *play-withs,* but who sought to know it for the gratification of knowing.

As science has grown, so, inevitably, has the ignorance of those who do not know about it. Within the mind of anyone educated exclusively in artistic and literary disciplines, the area of darkness has spread enormously during the later twentieth century, blotting out most of modern knowledge. A new species of educated but benighted being has come into existence – a creature unprecedented in the history of learning, where education has usually aimed to eradicate ignorance. The most highly gifted members of this new species have generally been the most forthright in regretting their deprivation. 'Exclusion from the mode of thought which is habitually said to be the characteristic achievement of the modern age' is, lamented the distinguished American literary critic Lionel Trilling, 'bound to be experienced as a wound to our intellectual self-esteem.'

More recently, however, ignorance of science has acquired a degree of political correctness. The Green movement, blaming science for global pollution, has contributed to this. So has feminism, which has demonized science as the embodiment of

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the male will-to-power. Even supposing these attacks were justified, however, they would not constitute reasons for relinquishing science, rather the reverse. Countering the pollution that political misdirection of science has caused can only be achieved by scientific means. Even at its most basic level, the monitoring, protection and conservation of endangered plant and animal species is inevitably a scientific endeavour. Nor does the feminist complaint that science is dominated by male aims and attitudes justify the neglect or rejection of science by women. On the contrary, it makes urgently desirable the increased involvement of women in scientific education and research. This is the view put forward by one of the most cogent of the feminist critics, Evelyn Fox Keller, in her book *Reflections on Gender and Science* (1984). Herself a mathematical biophysicist, and a biographer of the Nobel prizewinning geneticist Barbara McClintock, Keller sees scientific knowledge as ideally 'a universal goal', rather than the expression of destructively masculine drives.

A text that has been utilized to reinforce feminist and other disparagements of science is Thomas S. Kuhn's *The Structure of Scientific Revolutions* (1962). This popularized the idea that scientists are not really as rational as they suppose, but follow cultural trends, shifting from one paradigm to another for reasons that have nothing to do with objective truth. A criticism of Kuhn's book often voiced by scientists is that in describing how beliefs came to be held it leaves out of account the question of their truth or falsehood.

The effect of these various devices for discrediting science has been to allow ignorance to appear not merely excusable but righteous. Teachers at British universities will know that most arts students happily forget what little science they learnt in their schooldays. Even if you are prepared for this, however, the extent of their ignorance can come as a shock. Recently, in an Oxford literature seminar, I cited John Donne's lines, where Donne observes that no one at the time he was writing (1612) knew how blood gets from one ventricle of the heart to the other. I asked the class how, in fact, it does. There were about thirty students present, all in their last year of study, all outstandingly intelligent, and none of them knew. One young man ventured haltingly that it might be 'by osmosis'. That the blood circulated round their bodies, they seemed unaware.

The annual hordes competing for places on arts courses in British universities, and the trickle of science applicants, testify to the abandonment of science among the young. Though most academics are wary of saying it straight out, the general consensus seems to be that arts courses are popular because

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they are easier, and that most arts students would simply not be up to the intellectual demands of a science course. On this issue, Sir Peter Medawar is worth quoting, since he is well qualified to judge, and he disagrees. Commenting on the career of James Watson, the young American who became world famous in 1953 when, with Crick, Wilkins and Franklin, he discovered the molecular structure of DNA, Medawar says:

> In England a schoolboy of Watson's precocity and style of genius would probably have been steered towards literary studies. It just so happens that during the 1950s, the first great age of molecular biology, the English schools of Oxford and particularly of Cambridge produced more than a score of graduates of quite outstanding ability – much more brilliant, inventive, articulate and dialectically skilful than most young scientists; right up in the Watson class. But Watson had one towering advantage over all of them: in addition to being extremely clever he had something important to be clever *about.* This is an advantage which scientists enjoy over most other people engaged in intellectual pursuits, and they enjoy it at all levels of capability. To be a first-rate scientist it is not necessary (and certainly not sufficient) to be extremely clever, anyhow in a pyrotechnic sense. One of the great social revolutions brought about by scientific research has been the democratization of learning. Anyone who combines strong common sense with an ordinary degree of imaginativeness can become a creative scientist, and a happy one besides, in so far as happiness depends upon being able to develop to the limit of one's abilities.

Medawar's remarks caused a considerable rumpus, especially his claim that scientists had something to be clever about whereas arts students had not. Surely, he was asked, he did not intend to imply that Shakespeare, Tolstoy, etc. were not proper subjects for cleverness? Less attention was paid to his claim that science could bring happiness, and not just to geniuses but to people of ordinary ability. Yet that was surely the vital part of his message. If young people are to be wooed back to science, it will not be done by telling them that if they continue to spurn it, Britain will face economic decline (true as that may be). But if scientists demonstrate by their writing that Medawar's promises of pleasure and self-fulfilment are true, they will not lack recruits.

The new generation of popular science-writers, whose work I have drawn on in this anthology, are the advance guard of that

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campaign. If readers ask, as they well might, what I, a professor of literature, think I am up to editing a science anthology, my answer is that I have done it for pleasure, self-fulfilment and (in Coleridge's words) 'the gratification of knowing'.

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# Prelude: The Misfit from Vinci

A left-handed, vegetarian, homosexual bastard, Leonardo da Vinci (1452–1519) contravened most of the accepted norms of his day. Reared by his peasant grandparents in a remote Tuscan village, he had minimal schooling. He was apprenticed as a painter because his illegitimacy debarred him from respectable professions. (Painting in fifteenth-century Tuscany was regarded not as 'creative art' but as a lowly trade, fit for the sons of peasants and artisans.) Lacking literary culture he was scorned in the highbrow Florence of the Medicis. This turned him towards science and observation. 'Anyone who invokes authors in discussion is not using his intelligence but his memory,' he contended.

He was insatiable for newness, both in art and science. His first known drawing was also the first true landscape drawing in western art. He was the first painter to omit haloes from the heads of figures from scripture and show them in ordinary domestic settings, and he was the first to paint portraits that showed the hands as well as the faces of sitters. His Leda (which does not survive) was the first modern painting inspired by pagan myth. His notebooks, of which over 5,000 pages survive, are all written backwards in mirror writing, and are dense with intricate drawings. They record his observations on geology, optics, acoustics, music, botany, mathematics, anatomy, engineering and hydraulics, together with plans for many inventions, including a bicycle, a tank, a machine gun, a folding bed, a diving suit, a parachute, contact lenses, a water-powered alarm clock, and plastics (made of eggs, glue and vegetable dyes).

It is true that Leonardo was not strictly a scientist, nor always as original as he seems. His war-machines had already been designed by a German engineer, Konrad Keyser; his 'automobile' by an Italian, Martini. Though he came close to formulating some scientific laws, his insights were sporadic and untested by experiment. He thought of looking at the moon through a telescope a century before Galileo (see p. 8), but he did not construct one. He knew no algebra, and made mistakes in simple arithmetic. His man-powered flying machine, designed to flap its wings like a bird, could never have flown. Apart from anything else, it must have weighed about 650 lbs (as against 72 lbs for *Daedalus 88,* the man-powered aircraft which flew 74 miles over the Aegean in 1988).

Despite these reservations his notebooks give an astonishing preview of the new world science was to open. The first of the following extracts, recording two autopsies he carried out in Florence on a very

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old man and a young child, has been called the first description of arteriosclerosis in the history of medicine. The second anticipates nineteenth-century geology (see p. 71) in deducing from fossil remains that the earth's present land-masses were once covered by sea. (The 'great horse' Leonardo refers to in this extract was his 7-metre-high bronze equestrian statue, planned for Lodovico Sforza in 1493, but never completed.) The third and fourth extracts show the sympathetic observation of birds, which inspired his interest in manned flight. The fifth illustrates Leonardo's irreverent humour and anatomical accuracy.

### *Autopsies*

A few hours before his death, this old man told me that he had lived a hundred years and that he felt no physical pain, only weakness; and thus, seated on a bed in the hospital of Santa Maria Novella [in Florence], without any movement or symptom of distress, he gently passed from life into death. I carried out the autopsy to determine the cause of such a calm death and discovered that it was the result of weakness produced by insufficiency of blood and of the artery supplying the heart and other lower members, which I found to be all withered, shrunken and desiccated. The other postmortem was on a child of two years, and here I discovered the case to be exactly opposite to that of the old man.

### *Submarine Traces*

Why are the bones of great fishes, and oysters and corals and various other shells and sea-snails, found on the high tops of mountains that border the sea, in the same way in which they are found in the depths of the sea? In the mountains of Parma and Piacenza, multitudes of shells and corals filled with worm-holes may be seen still adhering to the rocks, and when I was making the great horse at Milan a large sack of those which had been found in these parts was brought to my workshop by some peasants. The red stone of the mountains of Verona is found with shells all intermingled, which have become part of this stone. And if you should say that these shells have been and still constantly are being created in such places as these by the nature of the locality or by potency of the heavens in these spots, such an opinion cannot exist in brains possessed of any extensive powers of reasoning. Because the years of their growth are numbered upon the outer coverings of their shells; and both small and large ones may be seen; and these would not have grown without feeding, or fed without movement, and here [embedded in rock] they would not have been able to move... The peaks of the Apennines once stood up in a sea, in

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the form of islands surrounded by salt water, and above the plains of Italy where flocks of birds are flying today, fishes were once moving in large shoals.

### *Birds' Eyes*

The eyes of all animals have pupils which have power to increase or diminish of their own accord, according to the greater or lesser light of the sun or other luminary. In birds, however, the difference is greater, and especially with nocturnal birds of the owl species, such as the long-eared, the white and the brown owls; for with these the pupil increases until it almost covers the whole eye, or diminishes to the size of a grain of millet, preserving all the time its round shape. In the horned owl, which is the largest nocturnal bird, the power of vision is so much increased that even in the faintest glimmer of night, which we call darkness, it can see more distinctly than we in the radiance of noon.

### *Flight*

A bird is an instrument working according to a mathematical law, which instrument it is within the capacity of man to reproduce, with all its movements. A bird maintains itself in the air by imperceptible balancing, when near to the mountains or lofty ocean crags. It does this by means of the curves of the winds, which as they strike against these projections, being forced to preserve their first impetus, bend their straight course towards the sky, with divers revolutions, at the beginning of which the birds come to a stop, with their wings open, receiving underneath themselves the continual buffetings of the reflex courses of the winds.

### *The Penis*

It has dealings with human intelligence and sometimes displays an intelligence of its own; where a man may desire it to be stimulated it remains obstinate and follows its own course; and sometimes it moves on its own without permission or any thought by its owner. Whether one is awake or asleep, it does what it pleases; often the man is asleep and it is awake; often the man is awake and it is asleep; or the man would like it to be in action but it refuses; often it desires action and the man forbids it. That is why it seems that this creature often has a life and intelligence separate from that of the man, and it seems that man is wrong to be ashamed of giving it a name or showing it; that which he seeks to cover and hide he ought to expose solemnly like a priest at mass.

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Sources: 'Submarine Traces', 'Birds' Eyes' and 'Flight' are from *The Notebooks of Leonardo da Vinci,* Arranged, Rendered into English, and Introduced by Edward MacCurdy, 2 vols, London, Jonathan Cape, 1938. 'Autopsies' and 'The Penis' are from Serge Bramly, *Leonardo: The Artist and the Man,* translated by Sian Reynolds, London, Edward Burlingame Books (an imprint of HarperCollins Publishers), 1991.

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# Going inside the Body

1543 has a good claim to be the year when modern science began. It saw the publication of Copernicus' *On the Revolutions of the Heavenly Spheres* (see below p. 8) and of Andreas Vesalius' *On the Fabric of the Human Body* (generally known by its Latin title, the *Fabrica*). The text of this book – the foundation of modern anatomy – was accompanied by magnificent illustrations, designed by artists of the school of Titian, and cut on fine pearwood by Venetian block-cutters, which show the arteries, veins, muscles and nerves of the human body.

A well-off Belgian doctor's son, Vesalius (1514–64) had been given the best medical education available, studying at Louvain, Paris and Padua, where he became Professor of Anatomy at the age of 23. His mission was to rescue anatomy from the errors of the ancient Greek physician Galen, who still dominated medicine in the sixteenth century. Galen had had to depend on animal corpses for his knowledge of anatomy, and the prejudice against cutting up human bodies was still strong at the start of Vesalius' career. At Louvain, wishing to construct a human skeleton, he stole the remains of a malefactor from a gibbet outside the city. In order to satisfy his curiosity about the fluid in the pericardium, he contrived to be present when a criminal was quartered alive and (he recalls) carried off for study 'the still-pulsating heart with the lung and the rest of the viscera'. Once he was established in Padua, the magistrates supplied him with corpses fresh from the gallows, and executions were timed to coincide with his anatomy lessons.

Unlike previous professors he did not sit aloof on his throne while a barber surgeon cut up the cadaver, but carried out the dissection himself. The title page of the *Fabrica* – as if to emphasize masculine conquest of 'Mother Nature' – shows him handling the abdominal organs of a naked, cut-open woman, surrounded by tiers of eager male spectators. The woman, Vesalius records, had tried to cheat the gallows by declaring herself pregnant.

By chance an eyewitness account of Vesalius' first public anatomy classes survives, written by a German student, Baldasar Heseler. Held in Bologna in 1540, the classes covered the dissection of three human corpses, but the last class was on a living dog. The question which puzzles the students in this extract had already been answered by Vesalius at the end of his previous lecture, where he pointed out that it was when the heart contracted that it pumped blood into the pulmonary artery – so evidently the students had not been listening.

Finally, he took a dog (which was now the fifth or perhaps the

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sixth killed in our anatomy). He bound it with ropes to a small beam so that it could not move, similarly he tied his jaws so that it could not bite. Here, Domini, he said, you will see in this living dog the function of the nervi reversivi, and you will hear how the dog will bark as long as these nerves are not injured. I shall cut off one nerve, and half of the voice will disappear, then I shall cut the other nerve, and the voice will no longer be heard. When he had opened the dog, he quickly found the nervi reversivi around the arteries, and all happened as he said. The bark of the dog disappeared when he had by turn cut off the nervi reversivi, and only the breathing remained. But, he said, it can still quite well bite, do not let its jaws free, hold it strongly. Finally, he said, I shall proceed to the heart, so that you shall see its movement, and feel its warmth, and so that you shall here around the ilium feel the pulse with one hand, and with the other the movement of the heart. And please, tell me, what its movement is, whether the arteries are compressed when the heart is dilated, or whether they in the same time also have the same movement as the heart. I saw how the heart of the dog bounded upwards, and when it no longer moved, the dog instantly died. Those mad Italians pulled the dog at all sides so that nobody could really feel these two movements. But some students asked Vesalius what the true fact about these movements was, what he himself thought, whether the arteries followed the movement of the heart, or whether they had a movement different from that of the heart. Vesalius answered: I do not want to give my opinion, please do feel yourselves with your own hands and trust them. He was said always to be so little communicative.

When seventeenth-century poets thought of the human body they still thought of Vesalius' anatomy pictures and executed criminals, as this extract from Andrew Marvell's *Dialogue between the Soul and Body* suggests. Like Vesalius, Marvell considers the heart 'double', formed only of the two ventricles. Vesalius regarded the right atrium as a passageway for the vena cava, and the left as part of the pulmonary vein.

> O who shall from this dungeon raise
> A soul enslaved so many ways? …
> A soul hung up, as 'twere, in chains
> Of nerves and arteries and veins.
> Tortured, besides each other part,
> In a vain head and double heart.

Sources: Vesalius translation (slightly altered) from *Andreas Vesalius' First*

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*Public Anatomy at Bologna, 1540. An Eyewitness Report* By Baldasar Heseler, ed. Ruben Eriksson, Uppsala and Stockholm, Almquist & Wiksells Boktryckeri AB, 1959.

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# Galileo and the Telescope

Until the sixteenth century the accepted model of the universe was that developed by the second-century Alexandrian astrologer Ptolemy. According to this, the sun and the planets revolved round the earth. Over the centuries, complex adjustments were added to Ptolemy's system to make it fit astronomical observations.

The Pole Nicolaus Copernicus (1473–1543), a canon of the cathedral church at Frauenberg, and an amateur astronomer, put forward the hypothesis (in his book *On the Revolutions of the Heavenly Spheres,* published in 1543) that the earth moved, and went round the sun, which remained stationary. This contradicted several biblical texts, for example Joshua 10: 12–13, where Joshua commands the sun to stand still, implying that it normally moves. However the Church did not object. Copernicus dedicated his work to Pope Paul III and a cardinal and a bishop were among friends who urged him to publish. His theory was regarded as a harmless mathematical speculation. Most people did not take it seriously. Martin Luther spoke for the general public: 'This fool wishes to reverse the entire science of astronomy, but sacred scripture tells us that Joshua commanded the sun to stand still, and not the earth.'

With the advent of the telescope, however, observation replaced theory, and the old map of the heavens could be shown to be false. The inventor of the telescope is not known, but it was probably an obscure Dutch spectacle-maker living in Middelburg, Hans Lippershey. There is a story that, around 1600, two children were playing with lenses in his shop and found that by holding two together they could magnify the church weathervane. This led him to construct a simple telescope. By 1609 telescopes, under the name of 'Dutch trunks', were being made and sold in several European cities, including Venice, Padua, Paris and London.

Galileo Galilei (1564–1642) was a skilful instrument-maker and Professor of Mathematics at Padua University. To eke out his meagre salary, he kept a small shop in Padua, selling scientific instruments. About May 1609, he heard about telescopes and began constructing them. They were regarded as chiefly useful for observation on land or at sea. But it occurred to him to look at the sky through one. He published the astonishing results in March 1610 in a 24-page pamphlet called *The Starry Messenger* (*Siderius Nuncius*). It was written in a tersely factual style no scholar had used before, and it fell like a bombshell on the learned world.

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About ten months ago a report reached my ears that a Dutchman had constructed a telescope, by the aid of which visible objects, although at a great distance from the eye of the observer, were seen distinctly as if near; and some proofs of its most wonderful performances were reported which some gave credence to, but others contradicted. A few days after, I received confirmation of the report in a letter written from Paris by a noble Frenchman, Jaques Badovere, which finally determined me to give myself up first to inquire into the principle of the telescope, and then to consider the means by which I might compass the invention of a similar instrument, which a little while after I succeeded in doing, through deep study of the theory of Refraction; and I prepared a tube, at first of lead, in the ends of which I fitted two glass lenses, both plane on one side, but on the other side one spherically convex, and the other concave. Then bringing my eye to the concave lens I saw objects satisfactorily large and near, for they appeared one-third of the distance off and nine times larger than when they are seen with the natural eye alone. I shortly afterwards constructed another telescope with more nicety, which magnified objects more than sixty times. At length, by sparing neither labour nor expense, I succeeded in constructing for myself an instrument so superior that objects seen through it appear magnified nearly a thousand times, and more than thirty times nearer than if viewed by the natural powers of sight alone.

It would be altogether a waste of time to enumerate the number and importance of the benefits which this instrument may be expected to confer, when used by land or sea. But without paying attention to its use for terrestrial objects, I betook myself to observations of the heavenly bodies; and first of all, I viewed the Moon as near as if it was scarcely two semi-diameters of the Earth distant. After the Moon, I frequently observed other heavenly bodies, both fixed stars and planets, with incredible delight; and, when I saw their very great number, I began to consider about a method by which I might be able to measure their distances apart, and at length I found one …

Now let me review the observations made by me during the two months just past, again inviting the attention of all who are eager for true philosophy to the beginnings which led to the sight of most important phenomena.

Let me speak first of the surface of the Moon, which is turned towards us. For the sake of being understood more easily, I distinguish two parts in it, which I call respectively the brighter and the darker. The brighter part seems to surround

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and pervade the whole hemisphere; but the darker part, like a sort of cloud, discolours the Moon's surface and makes it appear covered with spots. Now these spots, as they are somewhat dark and of considerable size, are plain to every one, and every age has seen them, wherefore I shall call them *great* or *ancient* spots, to distinguish them from other spots, smaller in size, but so thickly scattered that they sprinkle the whole surface of the Moon, but especially the brighter portion of it. These spots have never been observed by any one before me; and from my observations of them, often repeated, I have been led to that opinion which I have expressed, namely, that I feel sure that the surface of the Moon is not perfectly smooth, free from inequalities and exactly spherical, as a large school of philosophers considers with regard to the Moon and the other heavenly bodies, but that, on the contrary, it is full of inequalities, uneven, full of hollows and protuberances, just like the surface of the Earth itself, which is varied everywhere by lofty mountains and deep valleys.

The appearances from which we may gather these conclusions are of the following nature: – On the fourth or fifth day after new-moon, when the Moon presents itself to us with bright horns, the boundary which divides the part in shadow from the enlightened part does not extend continuously in an ellipse, as would happen in the case of a perfectly spherical body, but it is marked out by an irregular, uneven, and very wavy line … for several bright excrescences, as they may be called, extend beyond the boundary of light and shadow into the dark part, and on the other hand pieces of shadow encroach upon the light: – nay, even a great quantity of small blackish spots, altogether separated from the dark part, sprinkle everywhere almost the whole space which is at the time flooded with the Sun's light, with the exception of that part alone which is occupied by the great and ancient spots. I have noticed that the small spots just mentioned have this common characteristic always and in every case, that they have the dark part towards the Sun's position, and on the side away from the Sun they have brighter boundaries, as if they were crowned with shining summits. Now we have an appearance quite similar on the Earth about sunrise, when we behold the valleys, not yet flooded with light, but the mountains surrounding them on the side opposite to the Sun already ablaze with the splendour of his beams; and just as the shadows in the hollows of the Earth diminish in size as the Sun rises higher, so also these spots on the Moon lose their blackness as the illuminated part grows larger and larger. Again, not only are the boundaries of light and shadow in the Moon seen to be uneven and sinuous, but –

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and this produces still greater astonishment – there appear very many bright points within the darkened portion of the Moon, altogether divided and broken off from the illuminated tract, and separated from it by no inconsiderable interval, which, after a little while, gradually increase in size and brightness, and after an hour or two become joined on to the rest of the bright portion, now become somewhat larger; but in the meantime others, one here and another there, shooting up as if growing, are lighted up within the shaded portion, increase in size, and at last are linked on to the same luminous surface, now still more extended … Now, is it not the case on the Earth before sunrise, that while the level plain is still in shadow, the peaks of the most lofty mountains are illuminated by the Sun's rays? After a little while does not the light spread further, while the middle and larger parts of those mountains are becoming illuminated; and at length, when the Sun has risen, do not the illuminated parts of the plains and hills join together? The grandeur, however, of such prominences and depressions in the Moon seems to surpass both in magnitude and extent the ruggedness of the Earth's surface, as I shall hereafter show. And here I cannot refrain from mentioning what a remarkable spectacle I observed while the Moon was rapidly approaching her first quarter … A protuberance of the shadow, of great size, indented the illuminated part in the neighbourhood of the lower cusp; and when I had observed this indentation longer, and had seen that it was dark throughout, at length, after about two hours, a bright peak began to arise a little below the middle of the depression; this by degrees increased, and presented a triangular shape, but was as yet quite detached and separated from the illuminated surface. Soon around it three other small points began to shine, until, when the Moon was just about to set, that triangular figure, having now extended and widened, began to be connected with the rest of the illuminated part, and, still girt with the three bright peaks already mentioned, suddenly burst into the indentation of shadow like a vast promontory of light …

Galileo goes on to describe the greatly increased number of stars visible through his telescope. The number of stars visible to the naked eye could be counted. But his telescope 'set distinctly before the eyes other stars in myriads which have never been seen before, and which surpass the old, previously known, stars in number more than ten times'. Turning his telescope to the Milky Way, the nature of which had been in dispute for centuries, he was able to establish that it was 'a mass of innumerable stars planted in clusters'. He then went on to his most amazing discovery.

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Now touching the occurrents of the present, I send herewith unto his Majesty the strangest piece of news (as I may justly call it) that he hath ever yet received from any part of the world; which is the annexed book (come abroad this very day) of the Mathematical Professor at Padua, who by the help of an optical instrument (which both enlargeth and approximated the object) invented first in Flanders, and bettered by himself, hath discovered four new planets rolling about the sphere of Jupiter, besides many other unknown and lastly, that the moon is not spherical but endued with many prominences, and, which is of all the strangest, illuminated with the solar light by reflection from the body of the earth, as he seemeth to say. So as upon the whole subject he hath first overthrown all former astronomy and next all astrology. For the virtue of these new planets must needs vary the judicial part, and why may there not be yet more?

Galileo became an instant celebrity. He christened the moons of Jupiter 'the Medicean planets' after Grand Duke Cosimo II de' Medici, who became his patron. Invited to Rome in triumph, he was received in audience by Pope Paul V, who refused to let him kneel, and at a grand banquet in his honour his optical instrument was dignified by the Greek name 'telescope' – a title conferred by the Marquis of Monticelli.

Though Galileo had been a convinced Copernican from his early years, he had tactfully said little about the Copernican system in *The Starry Messenger.* But he became less guarded with time, and the Church, awakening to the danger of the new ideas, became less tolerant. In 1632, when he published his Copernican *Dialogue on the Two Chief World Systems,* he was brought to trial before the Inquisition, found guilty, and sentenced to an indefinite term of imprisonment. Under threat of torture, he made a public abjuration.

I, Galileo, son of the late Vincenzo Galilei, Florentine, aged seventy years, arraigned personally before this tribunal and kneeling before you, Most Eminent and Reverend Lord Cardinals Inquisitors-General against heretical pravity throughout the entire Christian commonwealth, having before my eyes and touching with my hands the Holy Gospels, swear that I have always believed, do believe, and by God's help will in the future believe all that is held, preached, and taught by the Holy Catholic and Apostolic Church. But, whereas – after an injunction had been judicially intimated to me by this Holy Office to the effect that I must altogether abandon the false opinion that the Sun is the center of the world and immovable and that the Earth is not the center of the world and moves and that I must not hold, defend, or teach in any way whatsoever,

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verbally or in writing, the said false doctrine, and after it had been notified to me that the said doctrine was contrary to Holy Scripture – I wrote and printed a book in which I discuss this new doctrine already condemned and adduce arguments of great cogency in its favour without presenting any solution of these, I have been pronounced by the Holy Office to be vehemently suspected of heresy, that is to say, of having held and believed that the Sun is the center of the world and immovable and that the Earth is not the center and moves.

Therefore, desiring to remove from the minds of your Eminences, and of all faithful Christians, this vehement suspicion justly conceived against me, with sincere heart and unfeigned faith I abjure, curse, and detest the aforesaid errors and heresies and generally every other error, heresy, and sect whatsoever contrary to the Holy Church, and I swear that in future I will never again say or assert, verbally or in writing, anything that might furnish occasion for a similar suspicion regarding me; but, should I know any heretic or person suspected of heresy, I will denounce him to this Holy Office.

Confined in a secluded house at Arcetri, near Florence, the old and now blind Galileo was visited, two years before his death, by the young English poet, John Milton, who recalled the meeting in his classic defence of press freedom *Areopagitica* (1644): 'There it was that I found and visited the famous Galileo, grown old, a prisoner of the Inquisition, for thinking in Astronomy otherwise than the Franciscan and Dominican licensers thought.' In *Paradise Lost* Milton compares the fallen Satan's huge shield, dimly seen amid the murk of Hell, to the strange giant moon that Galileo ('the Tuscan artist') first saw through his telescope from the hills of Fiesole ('Fesole') or from the valley of the Arno ('Valdarno') where Florence stands:

> the broad circumference
> Hung on his shoulders like the moon, whose orb
> Through optic glass the Tuscan artist views
> At evening from the top of Fesole,
> Or in Valdarno, to descry new lands,
> Rivers or mountains in her spotty globe.

However, the universe in Milton's epic is the old earth-centred one, and when Adam asks a visiting angel for an astronomy lesson he is told that God has deliberately put such matters as whether the earth moves round the sun beyond men's grasp:

> He his fabric of the heavens
> Hath left to their disputes, perhaps to move
> His laughter at their quaint opinions wide.

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Sources: *The Sidereal Messenger of Galileo Galilei,* ed. and trans. Edward Strafford Carlos, London, Rivingtons, 1880, and *The Life and Letters of Sir Henry Wotton,* ed. Logan Pearsall Smith, Oxford, Clarendon Press, 1907.

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# William Harvey and the Witches

In 1612 the poet John Donne wrote:

> Knows't thou how blood, which to the heart doth flow,
> Doth from one ventricle to the other go?

This was a rhetorical question – for no one did know. A common idea was that the central division of the heart (the septum) had holes through which the blood passed – though Vesalius had shown it had not. William Harvey (1578–1657), who probably knew Donne, solved this mystery with his discovery of the circulation of the blood. He was already lecturing about this at the College of Physicians in London in 1615, though he did not publish it until 1628. Even then, he records, many medical experts thought his great discovery 'crack-brained', and some, like René Descartes, stuck to the idea that the heart was a kind of furnace rather than, as Harvey had shown, a pump made of muscle.

As private physician to Charles I, Harvey looked after the two royal princes at the Battle of Edgehill, during which he sat under a hedge reading a book. His royal appointment also involved him in the affair of the Lancashire witches, recounted here by his biographer Geoffrey Keynes, which illustrates the gradual advance of science over superstition in the seventeenth century.

It was in 1633 that the events took place in Pendle Forest near Burnley in Lancashire that led to Harvey's being called as a witness in the following year. This remote area in the north-west had been for some years agitated by a series of crimes attributed to witches, gossip leading to fanciful accusations conceived in the fertile brains of imaginative children or even taught them by their elders. The particular story that ultimately concerned Harvey began on 10 February 1633. A boy of 11 named Edmund Robinson made an elaborate deposition before two Justices of the Peace, Richard Shutleworth and John Starkey, at Padiham, alleging that on All Saints Day last (1 November 1632) he was gathering wild plums in Wheatley Lane, when he saw two greyhounds, one brown the other black, running in his direction over the next field. Each dog, he noticed, had a collar which 'did shine like gold', but though each had a string attached there was no one with them. At the same moment he saw a hare, and, thinking to set the dogs off after it, cried 'Loo, loo, loo', but they would not run. This

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angered him, and tying them by their strings to a bush, he beat them with a stick. Thereupon the black dog stood up in the person of the wife of one Dickenson, and the brown dog as a small boy he did not know. In his fright Robinson made to run away, but was stopped by the woman, who, producing a silver coin from her pocket, offered to give it to him if he would hold his tongue. This he refused, saying, ‘Nay, thou art a witch’. She then pulled from her pocket a sort of bridle that jingled, put it on the head of the boy that had been a dog, who then turned into a white horse. Seizing young Robinson, the woman mounted him on the horse in front of her and rode with him to a house called Hoarstones, a locality well known as a gathering place for witches. Many other people then came riding up on horses of various colours to the number of about threescore, and meat was roasted. A young woman tried to make him eat some of this and to drink something out of a glass, but he refused after the first taste of it. He then saw various people go into a neighbouring barn, where six of them kneeled and pulled on ropes fastened to the roof. This brought down smoking flesh, lumps of butter, and milk, which they caught in basins. Then six more people repeated the process, making such fearful faces that he stole out in terror and ran home, where he told his father that he had also seen the woman pricking pictures with thorns. When it was noticed that the boy had escaped, a party of people, several of whom he named, started in pursuit and had nearly caught up with him at a place called Boggard-hole, when two horsemen came up and rescued him. On the same evening Robinson’s father sent him to tie up two cows in their stalls, and on the way, in a field called the Ellers, he met another boy who picked a quarrel and made him fight until his ears were made very bloody. Looking down he saw that the aggressor had a cloven foot, which aroused fresh fears. He ran on to find the cows and saw the light of a lantern; thinking it was carried by friends he ran towards it only to find a woman on a bridge, whom he recognized, and turned back to meet again the boy with the cloven foot, who gave him a blow on the back and made him cry. The boy’s father in confirmation of the story said he had gone to look for him and found him in a state of terror and crying pitifully, so that he did not recover for nearly a quarter of an hour. In his deposition to the magistrates the boy gave the names of seventeen persons whom he knew as present at Hoarstones and said he could recognize others …

The boy was taken round by his father to various churches in the district and identified many more people among the congregations, money being paid for his services. It so happened that at the church of Kildwick, where he was taken,

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that any suche thinge haith ever beene.

On the body of Margaret Johnson wee fynd two things maye be called teats the one betweene her secretts and the ffundament on the edge thereof the other on the middle of her left buttocke. The first in shape lyke to the teate of a Bitche, but in our judgements nothinge but the skin of the ffundament drawen out as yt wilbe after the pyles or applicacion of leeches. The seacond is lyke the nipple or teate of a woman's breast but of the same colour with the rest of the skin without any hollowness or yssue for any bloode or juyce to come from thence.

*Midwives*

| | |
|---|---|
| Margryt Franses | Anna Ashwell |
| Aurelia Molins | Ffrancis Palmer |
| Amis Willuby | Katheren Manuche |
| Rebecke Layne | Clifton |
| Sibell Ffellipps | Joane Sensions |

*Surgeons*

Alexander Read

| | |
|---|---|
| W. Clowes | Rich$^{d}$ Wateson |
| Alex. Baker | Ja. Molins |
| Ric. Mapes | Henry Blackley |

This statement, bearing every mark of Harvey's precise and logical mind, was not signed by himself, Alexander Read having taken his place. As a result four of the seven witches were pardoned by the King, who had himself seen them. Subsequently the boy Robinson, having been brought to London with his father, was re-examined alone and confessed to being an impostor. His father, he said, and some others had taught him what he was to say with a view to making some money out of the story; in fact at the time of the supposed meeting at Hoarstones he was some distance away gathering plums in another man's orchard.

Source: Geoffrey Keynes, *The Life of William Harvey,* London, Oxford University Press, 1966.

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# The Hunting Spider

Robert Hooke (1635–1703) was curator of experiments at the Royal Society. An astronomer, physicist and naturalist, he assisted Robert Boyle in constructing the first air pump. His *Micrographia* (1665) contains the earliest illustrations of objects enlarged under the microscope – the crystal structure of snowflakes, a louse, a flea, a weevil, etc. It also contains the first scientific use of the word ‘cell’, to describe the microscopic honeycomb cavities in cork.

Only about half the world’s spiders spread webs to catch prey. The rest hunt or ambush. Hooke’s description reflects his close observation of the natural world.

The hunting spider is a small grey spider, prettily bespecked with black spots all over its body, which the microscope discovers to be a kind of feathers, like those on butterflies’ wings or the body of the white moth. Its gait is very nimble, by fits, sometimes running and sometimes leaping, like a grasshopper almost, then standing still and setting itself on its hinder legs. It will very nimbly turn its body and look round itself every way. It has six very conspicuous eyes, two looking directly forwards, placed just before; two other, on either side of those, looking forward and sideways; and two other about the middle of the top of its back or head, which look backwards and sidewards. These seemed to be the biggest. The surface of them all was very black, spherical, purely polished, reflecting a very clear and distinct image of all the ambient objects, such as a window, a man’s hand, a white paper, or the like.

Hooke discussed hunting spiders with his friend, the English traveller, virtuoso and diarist John Evelyn (1620–1706) who sent him the following description of their behaviour in Italy. Evelyn’s brown spider is evidently a different species from Hooke’s (which is grey). He identifies it as one of the wolf spiders *(Lupi).* These belong to the family Lycosidae (the family to which the Tarantula and the common wolf spider *Pardosa amentata,* which can often be seen in English gardens sunbathing on rockeries, both belong). They get their name because they chase after their prey like wolves, and there are over 2,500 known species.

Of all the sorts of insects, there is none has afforded me more divertisements than the Venatores, which are a sort of Lupi,

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that have their dens in the rugged walls and crevices of our houses; a small, brown and delicately spotted kind of spiders, whose hinder legs are longer than the rest.

Such I did frequently observe at Rome, which espying a fly at three or four yards distance, upon the balcony (where I stood) would not make directly to her, but crawl under the rail, till being arrived to the Antipodes, it would steal up, seldom missing its aim; but if it chanced to want anything of being perfectly opposite, would at first peep immediately slide down again, till, taking better notice, it would come the next time exactly upon the fly's back. But if this happened not to be within a competent leap, then would this insect move so softly, as the very shadow of the gnomon [the upright arm of a sundial] seemed not to be more imperceptible, unless the fly moved; and then would the spider move also in the same proportion, keeping that just time with her motion, as if the same soul had animated both those little bodies; and whether it were forwards, backwards, or to either side, without at all turning her body, like a well managed horse: But if the capricious fly took wing, and pitched upon another place behind our huntress, then would the spider whirl its body so nimbly about, as nothing could be imagined more swift; by which means she always kept the head towards her prey, though to appearance as immovable as if it had been a nail driven into the wood, till by that indiscernible progress (being arrived within the sphere of her reach) she made a fatal leap (swift as lightning) upon the fly, catching him in the pole [head], where she never quitted hold till her belly was full, and then carried the remainder home. I have beheld them instructing their young ones how to hunt, which they would sometimes discipline for not well observing. But when any of the old ones did (as sometimes) miss a leap, they would run out of the field, and hide them in their crannies, as ashamed, and haply not be seen abroad for four or five hours after.

Source: Robert Hooke, *Micrographia* (1665).

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# Early Blood Transfusion

The belief that imbibing blood from another person can restore youth and vigour is very ancient, and there were many early attempts to put it into practice. In 1492 Pope Innocent VIII, when weak and in a coma, was given the blood of three young men, all of whom died. How the blood was administered is not known: probably by mouth.

After Harvey's discovery of the circulation of the blood (see p. 17) the possibility of transferring blood directly from the arteries of the donor to the veins of the recipient through a tube was investigated both in France and in England. On 14 November 1666 the minutes of the Royal Society record that:

> The experiment of transfusing the blood of one dog into another was made before the Society by Mr King and Mr Thomas Coxe, upon a little mastiff and a spaniel, with very good success, the former bleeding to death, and the latter receiving the blood of the other, and emitting so much of his own as to make him capable of receiving the other.

Samuel Pepys, a member of the Society, missed this experiment, but heard about it, and followed the fortunes of the surviving dog, reporting in his diary on 28 November that it was still 'in perfect good health'. The experiment had been masterminded by Robert Boyle, who explored the possible psychological effects of transfusion in a series of questions to the Society – whether a fierce dog could be tamed by receiving blood from a cowardly dog; whether a transfused dog would recognize its master, etc.

The first English blood transfusion into a human being took place on 23 November 1667. The Royal Society tried to procure 'some mad person in the hospital of Bedlam' for the purpose, but the Keeper of Bedlam declined, so the choice fell on Arthur Coga, a 'very freakish and extravagant' Bachelor of Divinity from Cambridge who, being 'indigent', was persuaded by a fee of one guinea to volunteer. The Society's secretary, Henry Oldenburg, recorded the result in a letter to Boyle.

On Thursday next, God willing, a report will be made of the good success of the first trial of transfusion practised on a man, which was by order of the Society, and the approbation of a number of physicians, performed on Saturday last in Arundel House, in the presence of many spectators, among whom were

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Mr Howard and both his sons, the bishop of Salisbury, four or five physicians, some parliament men, etc., by the management and operation of Dr Lower and Dr King, the latter of whom performed the chief part with great dexterity, and with so much ease to the patient, that he made not the least complaint, nor so much as any grimace during the whole time of the operation; in which the blood of a young sheep, to the quantity of about eight or nine ounces by conjecture, was transmitted into the great vein of the right arm, after the man had let out some six or seven ounces of his own blood. All which was done by the method of Dr King's, which I published in Num. 20 of the Transactions, without any change at all of it, save only in the shape of one of the silver pipes, for more conveniency. Having let out, before the transfusion, into a porringer, so much of the sheep's blood, as would run out in about a minute (which amounted to twelve ounces) to direct us as to the quantity to be transfused into the man, he, when he saw that florid arterial blood in the porringer, was so well pleased with it, that he took some of it upon a knife, and tasted it, and finding it of a good relish, he went the more couragiously to its transmission into his veins, taking a cup or two of sack before, and a glass of wormwood wine and a pipe of tobacco after the operation, which no more disordered him, both by his own confession, and by appearance to all bystanders, than it did any of those that were in the room with him. The pipe being taken out of the man, the blood of the sheep ran a very free stream, to assure the spectators of an uninterrupted course of blood.

The patient found himself very well upon it, his pulse better than before, and so his appetite. His sleep good, his body as soluble as usual, it being observed, that the same day of his operation he had three or four stools, as he used to have before. This morning our president (who by very pressing business could not be present in Arundel House) and I sent to see him pretty early, and found him a bed, very well, as he assured us, and more composed, as his host affirmed, than he had been before.

Coga wrote an account of his operation in Latin, and read it to the Society. Pepys, who was present, concluded that he was 'cracked a little in his head, though he speaks very reasonably and very well'. A second transfusion, this time of 14 ounces of sheep's blood, was given to Coga on 12 December 1667. Once more, he survived apparently unharmed. However, a patient of the French pioneer of blood transfusion Jean Denis, who taught medicine at Montpellier, died following a transfusion in 1668, and this put a stop to transfusion into humans until the discovery of blood-group antigens and antibodies in

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legs near the head, and two little fins at the hindmost end of the body. Others were somewhat longer than an oval, and these were very slow a-moving, and few in number. These animalcules had divers colours, some being whitish and transparent; others with green and very glittering little scales; others again were green in the middle, and before and behind white; others yet were ashen grey. And the motion of most of these animalcules in the water was so swift, and so various upwards, downwards, and round about, that 'twas wonderful to see: and I judge that some of these little creatures were above a thousand times smaller than the smallest ones I have ever yet seen, upon the rind of cheese, in wheaten flour, mould, and the like.

Source: *Antony van Leeuwenhoek and His 'Little Animals',* ed. trans. and introduced by Clifford Dobell, New York, Russell & Russell Inc., 1958.

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