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The Most Precious Thing

All our science, measured against reality, is primitive and childlike - and yet it is the most precious thing we have.
Albert Einstein (1879-1955)

As I got off the plane, he was waiting for me, holding up a scrap of cardboard with my name scribbled on it. I was on my way to a conference of scientists and TV broadcasters devoted to the seemingly hopeless prospect of improving the presentation of science on commercial television. The organizers had kindly sent a driver.

'Do you mind if I ask you a question?' he said as we waited for my bag.

No, I didn't mind.

'Isn't it confusing to have the same name as that scientist guy?'

It took me a moment to understand. Was he pulling my leg? Finally, it dawned on me.

'I *am* that scientist guy,' I answered.

He paused and then smiled. 'Sorry. That's my problem. I thought it was yours too.'

He put out his hand. 'My name is William F. Buckley.' (Well, he wasn't *exactly* William F. Buckley, but he did bear the name of a contentious and well-known TV interviewer, for which he doubtless took a lot of good-natured ribbing.)

As we settled into the car for the long drive, the windshield

wipers rhythmically thwacking, he told me he was glad I was 'that scientist guy' - he had so many questions to ask about science. Would I mind?

No, I didn't mind.

And so we got to talking. But not, as it turned out, about science. He wanted to talk about frozen extraterrestrials languishing in an Air Force base near San Antonio, 'channelling' (a way to hear what's on the minds of dead people - not much, it turns out), crystals, the prophecies of Nostradamus, astrology, the shroud of Turin . . . He introduced each portentous subject with buoyant enthusiasm. Each time I had to disappoint him:

'The evidence is crummy,' I kept saying. 'There's a much simpler explanation.'

He was, in a way, widely read. He knew the various speculative nuances on, let's say, the 'sunken continents' of Atlantis and Lemuria. He had at his fingertips what underwater expeditions were supposedly just setting out to find the tumbled columns and broken minarets of a once-great civilization whose remains were now visited only by deep sea luminescent fish and giant kraken. Except . . . while the ocean keeps many secrets, I knew that there isn't a trace of oceanographic or geophysical support for Atlantis and Lemuria. As far as science can tell, they never existed. By now a little reluctantly, I told him so.

As we drove through the rain, I could see him getting glummer and glummer. I was dismissing not just some errant doctrine, but a precious facet of his inner life.

And yet there's so much in real science that's equally exciting, more mysterious, a greater intellectual challenge - as well as being a lot closer to the truth. Did he know about the molecular building blocks of life sitting out there in the cold, tenuous gas between the stars? Had he heard of the footprints of our ancestors found in 4-million-year-old volcanic ash? What about the raising of the Himalayas when India went crashing into Asia? Or how viruses, built like hypodermic syringes, slip their DNA past the host organism's defences and subvert the reproductive machinery of cells; or the radio search for extraterrestrial intelligence; or the newly discovered ancient civilization of Ebla that advertised the virtues of Ebla beer? No, he hadn't heard. Nor did he know, even

vaguely, about quantum indeterminacy, and he recognized DNA only as three frequently linked capital letters.

Mr 'Buckley' - well-spoken, intelligent, curious - had heard virtually nothing of modern science. He had a natural appetite for the wonders of the Universe. He *wanted* to know about science. It's just that all the science had gotten filtered out before it reached him. Our cultural motifs, our educational system, our communications media had failed this man. What society permitted to trickle through was mainly pretence and confusion. It had never taught him how to distinguish real science from the cheap imitation. He knew nothing about how science works.

There are hundreds of books about Atlantis - the mythical continent that is said to have existed something like 10,000 years ago in the Atlantic Ocean. (Or somewhere. A recent book locates it in Antarctica.) The story goes back to Plato, who reported it as hearsay coming down to *him* from remote ages. Recent books authoritatively describe the high level of Atlantean technology, morals and spirituality, and the great tragedy of an entire populated continent sinking beneath the waves. There is a 'New Age' Atlantis, 'the legendary civilization of advanced sciences,' chiefly devoted to the 'science' of crystals. In a trilogy called *Crystal Enlightenment* by Katrina Raphaell - the books mainly responsible for the crystal craze in America - Atlantean crystals read minds, transmit thoughts, are the repositories of ancient history and the model and source of the pyramids of Egypt. Nothing approximating evidence is offered to support these assertions. (A resurgence of crystal mania may follow the recent finding by the real science of seismology that the inner core of the Earth may be composed of a single, huge, nearly perfect crystal - of iron.)

A few books - Dorothy Vitaliano's *Legends of the Earth,* for example - sympathetically interpret the original Atlantis legends in terms of a small island in the Mediterranean that was destroyed by a volcanic eruption, or an ancient city that slid into the Gulf of Corinth after an earthquake. This, for all we know, may be the source of the legend, but it is a far cry from the destruction of a continent on which had sprung forth a preternaturally advanced technical and mystical civilization.

What we almost never find - in public libraries or newsstand

magazines or prime-time television programmes - is the evidence from sea floor spreading and plate tectonics, and from mapping the ocean floor which shows quite unmistakably that there could have been no continent between Europe and the Americas on anything like the timescale proposed.

Spurious accounts that snare, the gullible are readily available. Sceptical treatments are much harder to find. Scepticism does not sell well. A bright and curious person who relies entirely on popular culture to be informed about something like Atlantis is hundreds or thousands of times more likely to come upon a fable treated uncritically than a sober and balanced assessment.

Maybe Mr Buckley should know to be more sceptical about what's dished out to him by popular culture. But apart from that, it's hard to see how it's his fault. He simply accepted what the most widely available and accessible sources of information claimed was true. For his naivete, he was systematically misled and bamboozled.

Science arouses a soaring sense of wonder. But so does pseudoscience. Sparse and poor popularizations of science abandon ecological niches that pseudoscience promptly fills. If it were widely understood that claims to knowledge require adequate evidence before they can be accepted, there would be no room for pseudoscience. But a kind of Gresham's Law prevails in popular culture by which bad science drives out good.

All over the world there are enormous numbers of smart, even gifted, people who harbour a passion for science. But that passion is unrequited. Surveys suggest that some 95 per cent of Americans are 'scientifically illiterate'. That's just the same fraction as those African Americans, almost all of them slaves, who were illiterate just before the Civil War - when severe penalties were in force for anyone who taught a slave to read. Of course there's a degree of arbitrariness about any determination of illiteracy, whether it applies to language or to science. But anything like 95 per cent illiteracy is extremely serious.

Every generation worries that educational standards are decaying. One of the oldest short essays in human history, dating from Sumer some 4,000 years ago, laments that the young are disastrously more ignorant than the generation immediately preceding.

Twenty-four hundred years ago, the ageing and grumpy Plato, in Book VII of the *Laws,* gave his definition of scientific illiteracy:

> Who is unable to count one, two, three, or to distinguish odd from even numbers, or is unable to count at all, or reckon night and day, and who is totally unacquainted with the revolution of the Sun and Moon, and the other stars . . . All freemen, I conceive, should learn as much of these branches of knowledge as every child in Egypt is taught when he learns the alphabet. In that country arithmetical games have been invented for the use of mere children, which they learn as pleasure and amusement . . . I . . . have late in life heard with amazement of our ignorance in these matters; to me we appear to be more like pigs than men, and I am quite ashamed, not only of myself, but of all Greeks.

I don't know to what extent ignorance of science and mathematics contributed to the decline of ancient Athens, but I know that the consequences of scientific illiteracy are far more dangerous in our time than in any that has come before. It's perilous and foolhardy for the average citizen to remain ignorant about global warming, say, or ozone depletion, air pollution, toxic and radioactive wastes, acid rain, topsoil erosion, tropical deforestation, exponential population growth. Jobs and wages depend on science and technology. If our nation can't manufacture, at high quality and low price, products people want to buy, then industries will continue to drift away and transfer a little more prosperity to other parts of the world. Consider the social ramifications of fission and fusion power, supercomputers, data 'highways', abortion, radon, massive reductions in strategic weapons, addiction, government eavesdropping on the lives of its citizens, high-resolution TV, airline and airport safety, foetal tissue transplants, health costs, food additives, drugs to ameliorate mania or depression or schizophrenia, animal rights, superconductivity, morning-after pills, alleged hereditary antisocial predispositions, space stations, going to Mars, finding cures for AIDS and cancer.

How can we affect national policy - or even make intelligent decisions in our own lives - if we don't grasp the underlying

issues? As I write, Congress is dissolving its own Office of Technology Assessment - the only organization specifically tasked to provide advice to the House and Senate on science and technology. Its competence and integrity over the years have been exemplary. Of the 535 members of the US Congress, rarely in the twentieth century have as many as one per cent had any significant background in science. The last scientifically literate President may have been Thomas Jefferson.*

So how do Americans decide these matters? How do they instruct their representatives? Who in fact makes these decisions, and on what basis?

Hippocrates of Cos is the father of medicine. He is still remembered 2,500 years later for the Hippocratic Oath (a modified form of which is still here and there taken by medical students upon their graduation). But he is chiefly celebrated because of his efforts to bring medicine out of the pall of superstition and into the light of science. In a typical passage Hippocrates wrote: 'Men think epilepsy divine, merely because they do not understand it. But if they called everything divine which they do not understand, why, there would be no end of divine things.' Instead of acknowledging that in many areas we are ignorant, we have tended to say things like the Universe is permeated with the ineffable. A God of the Gaps is assigned responsibility for what we do not yet understand. As knowledge of medicine improved since the fourth century BC, there was more and more that we understood and less and less that had to be attributed to divine intervention - either in the causes or in the treatment of disease. Deaths in childbirth and infant mortality have decreased, lifetimes have lengthened, and medicine has improved the quality of life for billions of us all over the planet.

In the diagnosis of disease, Hippocrates introduced elements of the scientific method. He urged careful and meticulous

*** Although claims can be made for Theodore Roosevelt, Herbert Hoover and Jimmy Carter. Britain had such a Prime Minister in Margaret Thatcher. Her early studies in chemistry, in part under the tutelage of Nobel laureate Dorothy Hodgkin, were key to the UK's strong and successful advocacy that ozone-depleting CFCs be banned worldwide.**

observation: 'Leave nothing to chance. Overlook nothing. Combine contradictory observations. Allow yourself enough time.' Before the invention of the thermometer, he charted the temperature curves of many diseases. He recommended that physicians be able to tell, from present symptoms alone, the probable past and future course of each illness. He stressed honesty. He was willing to admit the limitations of the physician's knowledge. He betrayed no embarrassment in confiding to posterity that more than half his patients were killed by the diseases he was treating. His options of course were limited; the drugs available to him were chiefly laxatives, emetics and narcotics. Surgery was performed, and cauterization. Considerable further advances were made in classical times through to the fall of Rome.

While medicine in the Islamic world flourished, what followed in Europe was truly a dark age. Much knowledge of anatomy and surgery was lost. Reliance on prayer and miraculous healing abounded. Secular physicians became extinct. Chants, potions, horoscopes and amulets were widely used. Dissections of cadavers were restricted or outlawed, so those who practised medicine were prevented from acquiring first-hand knowledge of the human body. Medical research came to a standstill.

It was very like what the historian Edward Gibbon described for the entire Eastern Empire, whose capital was Constantinople:

> In the revolution of ten centuries, not a single discovery was made to exalt the dignity or promote the happiness of mankind. Not a single idea had been added to the speculative systems of antiquity, and a succession of patient disciples became in their turn the dogmatic teachers of the next servile generation.

Even at its best, pre-modern medical practice did not save many. Queen Anne was the last Stuart monarch of Great Britain. In the last seventeen years of the seventeenth century, she was pregnant eighteen times. Only five children were born alive. Only one of them survived infancy. He died before reaching adulthood, and before her coronation in 1702. There seems to be no evidence of some genetic disorder. She had the best medical care money could buy.

Diseases that once tragically carried off countless infants and

children have been progressively mitigated and cured by science - through the discovery of the microbial world, via the insight that physicians and midwives should wash their hands and sterilize their instruments, through nutrition, public health and sanitation measures, antibiotics, drugs, vaccines, the uncovering of the molecular structure of DNA, molecular biology, and now gene therapy. In the developed world at least, parents today have an enormously better chance of seeing their children live to adulthood than did the heir to the throne of one of the most powerful nations on Earth in the late seventeenth century. Smallpox has been wiped out worldwide. The area of our planet infested with malaria-carrying mosquitoes has dramatically shrunk. The number of years a child diagnosed with leukaemia can expect to live has been increasing progressively, year by year. Science permits the Earth to feed about a hundred times more humans, and under conditions much less grim, than it could a few thousand years ago.

We can pray over the cholera victim, or we can give her 500 milligrams of tetracycline every twelve hours. (There is still a religion, Christian Science, that denies the germ theory of disease; if prayer fails, the faithful would rather see their children die than give them antibiotics.) We can try nearly futile psychoanalytic talk therapy on the schizophrenic patient, or we can give him 300 to 500 milligrams a day of chlozapine. The scientific treatments are hundreds or thousands of times more effective than the alternatives. (And even when the alternatives seem to work, we don't actually know that they played any role: spontaneous remissions, even of cholera and schizophrenia, can occur without prayer and without psychoanalysis.) Abandoning science means abandoning much more than air conditioning, CD players, hair dryers and fast cars.

In hunter-gatherer, pre-agricultural times, the human life expectancy was about 20 to 30 years. That's also what it was in Western Europe in Late Roman and in Medieval times. It didn't rise to 40 years until around the year 1870. It reached 50 in 1915, 60 in 1930, 70 in 1955, and is today approaching 80 (a little more for women, a little less for men). The rest of the world is retracing the European increment in longevity. What is the cause of this stunning, unprecedented, humanitarian transition? The germ theory of disease, public health measures, medicines and medical

technology. Longevity is perhaps the best single measure of the physical quality of life. (If you're dead, there's little you can do to be happy.) This is a precious offering from science to humanity - nothing less than the gift of life.

But micro-organisms mutate. New diseases spread like wildfire. There is a constant battle between microbial measures and human countermeasures. We keep pace in this competition not just by designing new drugs and treatments, but by penetrating progressively more deeply toward an understanding of the nature of life - basic research.

If the world is to escape the direst consequences of global population growth and 10 or 12 billion people on the planet in the late twenty-first century, we must invent safe but more efficient means of growing food - with accompanying seed stocks, irrigation, fertilizers, pesticides, transportation and refrigeration systems. It will also take widely available and acceptable contraception, significant steps toward political equality of women, and improvements in the standards of living of the poorest people. How can all this be accomplished without science and technology?

I know that science and technology are not just cornucopias pouring gifts out into the world. Scientists not only conceived nuclear weapons; they also took political leaders by the lapels, arguing that *their* nation - whichever it happened to be - had to have one first. Then they manufactured over 60,000 of them. During the Cold War, scientists in the United States, the Soviet Union, China and other nations were willing to expose their own fellow citizens to radiation - in most cases without their knowledge - to prepare for nuclear war. Physicians in Tuskegee, Alabama, misled a group of veterans into thinking they were receiving medical treatment for their syphilis, when they were the untreated controls. The atrocious cruelties of Nazi doctors are well-known. Our technology has produced thalidomide, CFCs, Agent Orange, nerve gas, pollution of air and water, species extinctions, and industries so powerful they can ruin the climate of the planet. Roughly half the scientists on Earth work at least part-time for the military. While a few scientists are still perceived as outsiders, courageously criticizing the ills of society and providing early warnings of potential technological catastrophes, many

are seen as compliant opportunists, or as the willing source of corporate profits and weapons of mass destruction - never mind the long-term consequences. The technological perils that science serves up, its implicit challenge to received wisdom, and its perceived difficulty, are all reasons for some people to mistrust and avoid it. There's a *reason* people are nervous about science and technology. And so the image of the mad scientist haunts our world - down to the white-coated loonies of Saturday morning children's TV and the plethora of Faustian bargains in popular culture, from the eponymous Dr Faustus himself to *Dr Frankenstein, Dr Strangelove,* and *Jurassic Park.*

But we can't simply conclude that science puts too much power into the hands of morally feeble technologists or corrupt, power-crazed politicians and so decide to get rid of it. Advances in medicine and agriculture have saved vastly more lives than have been lost in all the wars in history.* Advances in transportation, communication and entertainment have transformed and unified the world. In opinion poll after opinion poll science is rated among the most admired and trusted occupations, despite the misgivings. The sword of science is double-edged. Its awesome power forces on all of us, including politicians, a new responsibility - more attention to the long-term consequences of technology, a global and transgenerational perspective, an incentive to avoid easy appeals to nationalism and chauvinism. Mistakes are becoming too expensive.

Do we care what's true? Does it matter?

> . . . where ignorance is bliss,
> 'Tis folly to be wise

wrote the poet Thomas Gray. But is it? Edmund Way Teale in his 1950 book *Circle of the Seasons* understood the dilemma better:

*** At a large dinner party recently, I asked the assembled guests - ranging in age, I guess, from thirties to sixties - how many of them would be alive today if not for antibiotics, cardiac pacemakers, and the rest of the panoply of modern medicine. Only one hand went up. It was not mine.**

> It is morally as bad not to care whether a thing is true or not, so long as it makes you feel good, as it is not to care how you got your money as long as you have got it.

It's disheartening to discover government corruption and incompetence, for example; but it is better *not* to know about it? Whose interest does ignorance serve? If we humans bear, say, hereditary propensities toward the hatred of strangers, isn't self-knowledge the only antidote? If we long to believe that the stars rise and set for us, that we are the reason there *is* a Universe, does science do us a disservice in deflating our conceits?

In *The Genealogy of Morals,* Friedrich Nietzsche, as so many before and after, decries the 'unbroken progress in the self-belittling of man' brought about by the scientific revolution. Nietzsche mourns the loss of 'man's belief in his dignity, his uniqueness, his irreplaceability in the scheme of existence'. For me, it is far better to grasp the Universe as it really is than to persist in delusion, however satisfying and reassuring. Which attitude is better geared for our long-term survival? Which gives us more leverage on our future? And if our naive self-confidence is a little undermined in the process, is that altogether such a loss? Is there not cause to welcome it as a maturing and character-building experience?

To discover that the Universe is some 8 to 15 billion and not 6 to 12 thousand years old* improves our appreciation of its sweep and grandeur; to entertain the notion that we are a particularly complex arrangement of atoms, and not some breath of divinity, at the very least enhances our respect for atoms; to discover, as now seems probable, that our planet is one of billions of other worlds in the Milky Way galaxy and that our galaxy is one of billions more, majestically expands the arena of what is possible;

*** 'No thinking religious person believes this. Old hat,' writes one of the referees of this book. But many 'scientific creationists' not only believe it, but are making increasingly aggressive and successful efforts to have it taught in the schools, museums, zoos, and textbooks. Why? Because adding up the 'begats', the ages of patriarchs and others in the Bible gives such a figure, and the Bible is 'inerrant'.**

to find that our ancestors were also the ancestors of apes ties us to the rest of life and makes possible important - if occasionally rueful - reflections on human nature.

Plainly there is no way back. Like it or not, we are stuck with science. We had better make the best of it. When we finally come to terms with it and fully recognize its beauty and its power, we will find, in spiritual as well as in practical matters, that we have made a bargain strongly in our favour.

But superstition and pseudoscience keep getting in the way, distracting all the 'Buckleys' among us, providing easy answers, dodging sceptical scrutiny, casually pressing our awe buttons and cheapening the experience, making us routine and comfortable practitioners as well as victims of credulity. Yes, the world *would* be a more interesting place if there were UFOs lurking in the deep waters off Bermuda and eating ships and planes, or if dead people could take control of our hands and write us messages. It would be fascinating if adolescents were able to make telephone handsets rocket off their cradles just by thinking at them, or if our dreams could, more often than can be explained by chance and our knowledge of the world, accurately foretell the future.

These are all instances of pseudoscience. They purport to use the methods and findings of science, while in fact they are faithless to its nature - often because they are based on insufficient evidence or because they ignore clues that point the other way. They ripple with gullibility. With the uninformed cooperation (and often the cynical connivance) of newspapers, magazines, book publishers, radio, television, movie producers and the like, such ideas are easily and widely available. Far more difficult to come upon, as I was reminded by my encounter with Mr 'Buckley', are the alternative, more challenging and even more dazzling findings of science.

Pseudoscience is easier to contrive than science, because distracting confrontations with reality - where we cannot control the outcome of the comparison - are more readily avoided. The standards of argument, what passes for evidence, are much more relaxed. In part for these same reasons, it is much easier to present pseudoscience to the general public than science. But this isn't enough to explain its popularity.

Naturally people try various belief systems on for size, to see if they help. And if we're desperate enough, we become all too willing to abandon what may be perceived as the heavy burden of scepticism. Pseudoscience speaks to powerful emotional needs that science often leaves unfulfilled. It caters to fantasies about personal powers we lack and long for (like those attributed to comic book superheroes today, and earlier, to the gods). In some of its manifestations, it offers satisfaction of spiritual hungers, cures for disease, promises that death is not the end. It reassures us of our cosmic centrality and importance. It vouchsafes that we are hooked up with, tied to, the Universe.* Sometimes it's a kind of halfway house between old religion and new science, mistrusted by both.

At the heart of some pseudoscience (and some religion also, New Age and Old) is the idea that wishing makes it so. How satisfying it would be, as in folklore and children's stories, to fulfil our heart's desire just by wishing. How seductive this notion is, especially when compared with the hard work and good luck usually required to achieve our hopes. The enchanted fish or the genie from the lamp will grant us three wishes - anything we want except more wishes. Who has not pondered - just to be on the safe side, just in case we ever come upon and accidentally rub an old, squat brass oil lamp - what to ask for?

I remember, from childhood comic strips and books, a top-hatted, moustachioed magician who brandished an ebony walking stick. His name was Zatara. He could make anything happen, anything at all. How did he do it? Easy. He uttered his commands backwards. So if he wanted a million dollars, he would say 'srallod noillim a em evig'. That's all there was to it. It was something like prayer, but much surer of results.

I spent a lot of time at age eight experimenting in this vein,

*** Although it's hard for me to see a more profound cosmic connection than the astonishing findings of modern nuclear astrophysics: except for hydrogen, all the atoms that make each of us up - the iron in our blood, the calcium in our bones, the carbon in our brains - were manufactured in red giant stars thousands of light years away in space and billions of years ago in time. We are, as I like to say, starstuff.**

commanding stones to levitate: 'esir, enots.' It never worked. I blamed my pronunciation.

Pseudoscience is embraced, it might be argued, in exact proportion as real science is misunderstood - except that the language breaks down here. If you've never heard of science (to say nothing of how it works), you can hardly be aware you're embracing pseudoscience. You're simply thinking in one of the ways that humans always have. Religions are often the state-protected nurseries of pseudoscience, although there's no reason why religions have to play that role. In a way, it's an artefact from times long gone. In some countries nearly everyone believes in astrology and precognition, including government leaders. But this is not simply drummed into them by religion; it is drawn out of the enveloping culture in which everyone is comfortable with these practices, and affirming testimonials are everywhere.

Most of the case histories I will relate in this book are American - because these are the cases I know best, not because pseudoscience and mysticism are more prominent in the United States than elsewhere. But the psychic spoonbender and extraterrestrial channeller Uri Geller hails from Israel. As tensions rise between Algerian secularists and Muslim fundamentalists, more and more people are discreetly consulting the country's 10,000 soothsayers and clairvoyants (about half of whom operate with a licence from the government). High French officials, including a former President of France, arranged for millions of dollars to be invested in a scam (the Elf-Aquitaine scandal) to find new petroleum reserves from the air. In Germany, there is concern about carcinogenic 'Earth rays' undetectable by science; they can be sensed only by experienced dowsers brandishing forked sticks. 'Psychic surgery' flourishes in the Philippines. Ghosts are something of a national obsession in Britain. Since World War Two, Japan has spawned enormous numbers of new religions featuring the supernatural. An estimated 100,000 fortune-tellers flourish in Japan; the clientele are mainly young women. Aum Shinrikyo, a sect thought to be involved in the release of the nerve gas sarin in the Tokyo subway system in March 1995, features

levitation, faith healing and ESP among its main tenets. Followers, at a high price, drank the 'miracle pond' water - from the bath of Asahara, their leader. In Thailand, diseases are treated with pills manufactured from pulverized sacred Scripture. 'Witches' are today being burned in South Africa. Australian peace-keeping forces in Haiti rescue a woman tied to a tree; she is accused of flying from rooftop to rooftop, and sucking the blood of children. Astrology is rife in India, geomancy widespread in China.

Perhaps the most successful recent global pseudoscience - by many criteria, already a religion - is the Hindu doctrine of transcendental meditation (TM). The soporific homilies of its founder and spiritual leader, the Maharishi Mahesh Yogi, can be seen on television in America. Seated in the yogi position, his white hair here and there flecked with black, surrounded by garlands and floral offerings, he has a *look*. One day while channel surfing we came upon this visage. 'You know who that is?' asked our four-year-old son. 'God.' The worldwide TM organization has an estimated valuation of $3 billion. For a fee they promise through meditation to be able to walk you through walls, to make you invisible, to enable you to fly. By thinking in unison they have, they say, diminished the crime rate in Washington DC and caused the collapse of the Soviet Union, among other secular miracles. Not one smattering of real evidence has been offered for any such claims. TM sells folk medicine, runs trading companies, medical clinics and 'research' universities, and has unsuccessfully entered politics. In its oddly charismatic leader, its promise of community, and the offer of magical powers in exchange for money and fervent belief, it is typical of many pseudosciences marketed for sacerdotal export.

At each relinquishing of civil controls and scientific education, another little spurt in pseudoscience occurs. Leon Trotsky described it for Germany on the eve of the Hitler takeover (but in a description that might equally have applied to the Soviet Union of 1933):

> Not only in peasant homes, but also in city skyscrapers, there lives alongside the twentieth century the thirteenth. A hundred million people use electricity and still believe in the

> magic powers of signs and exorcisms . . . Movie stars go to mediums. Aviators who pilot miraculous mechanisms created by man's genius wear amulets on their sweaters. What inexhaustible reserves they possess of darkness, ignorance and savagery!

Russia is an instructive case. Under the Tsars, religious superstition was encouraged, but scientific and sceptical thinking - except by a few tame scientists - was ruthlessly expunged. Under Communism, both religion and pseudoscience were systematically suppressed - except for the superstition of the state ideological religion. It was advertised as scientific, but fell as far short of this ideal as the most unself-critical mystery cult. Critical thinking - except by scientists in hermetically sealed compartments of knowledge - was recognized as dangerous, was not taught in the schools, and was punished where expressed. As a result, post-Communism, many Russians view science with suspicion. When the lid was lifted, as was also true of virulent ethnic hatreds, what had all along been bubbling subsurface was exposed to view. The region is now awash in UFOs, poltergeists, faith healers, quack medicines, magic waters and old-time superstition. A stunning decline in life expectancy, increasing infant mortality, rampant epidemic disease, subminimal medical standards and ignorance of preventive medicine all work to raise the threshold at which scepticism is triggered in an increasingly desperate population. As I write, the electorally most popular member of the Duma, a leading supporter of the ultranationalist Vladimir Zhirinovsky, is one Anatoly Kashpirovsky - a faith healer who remotely cures diseases ranging from hernias to AIDS by glaring at you out of your television set. His face starts stopped clocks.

A somewhat analogous situation exists in China. After the death of Mao Zedong and the gradual emergence of a market economy, UFOs, channelling and other examples of Western pseudoscience emerged, along with such ancient Chinese practices as ancestor worship, astrology and fortune telling - especially that version that involves throwing yarrow sticks and working through the hoary tetragrams of the *I Ching*. The government newspaper lamented that 'the superstition of feudal ideology is reviving in our

countryside'. It was (and remains) a rural, not primarily an urban, affliction.

Individuals with 'special powers' gained enormous followings. They could, they said, project Qi, the 'energy field of the Universe', out of their bodies to change the molecular structure of a chemical 2,000 kilometres away, to communicate with aliens, to cure diseases. Some patients died under the ministrations of one of these 'masters of Qi Gong' who was arrested and convicted in 1993. Wang Hongcheng, an amateur chemist, claimed to have synthesized a liquid, small amounts of which, when added to water, would convert it to gasoline or the equivalent. For a time he was funded by the army and the secret police, but when his invention was found to be a scam he was arrested and imprisoned. Naturally the story spread that his misfortune resulted not from fraud, but from his unwillingness to reveal his 'secret formula' to the government. (Similar stories have circulated in America for decades, usually with the government role replaced by a major oil or auto company.) Asian rhinos are being driven to extinction because their horns, when pulverized, are said to prevent impotence; the market encompasses all of East Asia.

The government of China and the Chinese Communist Party were alarmed by certain of these developments. On 5 December 1994, they issued a joint proclamation that read in part:

> [P]ublic education in science has been withering in recent years. At the same time, activities of superstition and ignorance have been growing, and antiscience and pseudoscience cases have become frequent. Therefore, effective measures must be applied as soon as possible to strengthen public education in science. The level of public education in science and technology is an important sign of the national scientific accomplishment. It is a matter of overall importance in economic development, scientific advance, and the progress of society. We must be attentive and implement such public education as part of the strategy to modernize our socialist country and to make our nation powerful and prosperous. Ignorance is never socialist, nor is poverty.

So pseudoscience in America is part of a global trend. Its causes, dangers, diagnosis and treatment are likely to be similar everywhere. Here, psychics ply their wares on extended television commercials, personally endorsed by entertainers. They have their own channel, the 'Psychic Friends Network'; a million people a year sign on and use such guidance in their everyday lives. For the chief executives of major corporations, for financial analysts, for lawyers and bankers there is a species of astrologer/soothsayer/psychic ready to advise on any matter. 'If people knew how many people, especially the very rich and powerful ones, went to psychics, their jaws would drop through the floor,' says a psychic from Cleveland, Ohio. Royalty has traditionally been vulnerable to psychic frauds. In ancient China and Rome astrology was the exclusive property of the emperor; any private use of this potent art was considered a capital offence. Emerging from a particularly credulous Southern California culture, Nancy and Ronald Reagan relied on an astrologer in private and public matters - unknown to the voting public. Some portion of the decision-making that influences the future of our civilization is plainly in the hands of charlatans. If anything, the practice is comparatively muted in America; its venue is worldwide.

As amusing as some of pseudoscience may seem, as confident as we may be that we would never be so gullible as to be swept up by such a doctrine, we know it's happening all around us. Transcendental meditation and Aum Shinrikyo seem to have attracted a large number of accomplished people, some with advanced degrees in physics or engineering. These are not doctrines for nitwits. Something else is going on.

What's more, no one interested in what religions are and how they begin can ignore them. While vast barriers may seem to stretch between a local, single-focus contention of pseudoscience and something like a world religion, the partitions are very thin. The world presents us with nearly insurmountable problems. A wide variety of solutions are offered, some of very limited worldview, some of portentous sweep. In the usual Darwinian natural selection of doctrines, some thrive for a time, while most quickly vanish. But a few - sometimes, as history has shown, the

most scruffy and least prepossessing among them - may have the power to change profoundly the history of the world.

The continuum stretching from ill-practised science, pseudo-science and superstition (New Age or Old), all the way to respectable mystery religion, based on revelation, is indistinct. I try not to use the word 'cult' in this book in its usual meaning of a religion the speaker dislikes, but try to reach for the headstone of knowledge - do they really know what they claim to know? Everyone, it turns out, has relevant expertise.

In certain passages of this book I will be critical of the excesses of theology, because at the extremes it is difficult to distinguish pseudoscience from rigid, doctrinaire religion. Nevertheless, I want to acknowledge at the outset the prodigious diversity and complexity of religious thought and practice over the millennia; the growth of liberal religion and ecumenical fellowship during the last century; and the fact that - as in the Protestant Reformation, the rise of Reform Judaism, Vatican II, and the so-called higher criticism of the Bible - religion has fought (with varying degrees of success) its own excesses. But in parallel to the many scientists who seem reluctant to debate or even publicly discuss pseudo-science, many proponents of mainstream religions are reluctant to take on extreme conservatives and fundamentalists. If the trend continues, eventually the field is theirs; they can win the debate by default.

One religious leader writes to me of his longing for 'disciplined integrity' in religion:

> We have grown far too sentimental . . . Devotionalism and cheap psychology on one side, and arrogance and dogmatic intolerance on the other distort authentic religious life almost beyond recognition. Sometimes I come close to despair, but then I live tenaciously and always with hope . . . Honest religion, more familiar than its critics with the distortions and absurdities perpetrated in its name, has an active interest in encouraging a healthy skepticism for its own purposes . . . There is the possibility for religion and science to forge a potent partnership against pseudo-science. Strangely, I think it would soon be engaged also in opposing pseudo-religion.

Pseudoscience differs from erroneous science. Science thrives on errors, cutting them away one by one. False conclusions are drawn all the time, but they are drawn tentatively. Hypotheses are framed so they are capable of being disproved. A succession of alternative hypotheses is confronted by experiment and observation. Science gropes and staggers toward improved understanding. Proprietary feelings are of course offended when a scientific hypothesis is disproved, but such disproofs are recognized as central to the scientific enterprise.

Pseudoscience is just the opposite. Hypotheses are often framed precisely so they are invulnerable to any experiment that offers a prospect of disproof, so even in principle they cannot be invalidated. Practitioners are defensive and wary. Sceptical scrutiny is opposed. When the pseudoscientific hypothesis fails to catch fire with scientists, conspiracies to suppress it are deduced.

Motor ability in healthy people is almost perfect. We rarely stumble and fall, except in young and old age. We can learn tasks such as riding a bicycle or skating or skipping, jumping rope or driving a car, and retain that mastery for the rest of our lives. Even if we've gone a decade without doing it, it comes back to us effortlessly. The precision and retention of our motor skills may, however, give us a false sense of confidence in our other talents. Our perceptions are fallible. We sometimes see what isn't there. We are prey to optical illusions. Occasionally we hallucinate. We are error-prone. A most illuminating book called *How We Know What Isn't So: The Fallibility of Human Reason in Everyday Life,* by Thomas Gilovich, shows how people systematically err in understanding numbers, in rejecting unpleasant evidence, in being influenced by the opinions of others. We're good in some things, but not in everything. Wisdom lies in understanding our limitations. 'For Man is a giddy thing,' teaches William Shakespeare. That's where the stuffy sceptical rigour of science comes in.

Perhaps the sharpest distinction between science and pseudoscience is that science has a far keener appreciation of human imperfections and fallibility than does pseudoscience (or 'inerrant' revelation). If we resolutely refuse to acknowledge where we are liable to fall into error, then we can confidently expect that error - even serious error, profound mistakes - will be our companion

forever. But if we are capable of a little courageous self-assessment, whatever rueful reflections they may engender, our chances improve enormously.

If we teach only the findings and products of science - no matter how useful and even inspiring they may be - without communicating its critical method, how can the average person possibly distinguish science from pseudoscience? Both then are presented as unsupported assertion. In Russia and China, it used to be easy. Authoritative science was what the authorities taught. The distinction between science and pseudoscience was made for you. No perplexities needed to be muddled through. But when profound political changes occurred and strictures on free thought were loosened, a host of confident or charismatic claims - especially those that told us what we wanted to hear - gained a vast following. Every notion, however improbable, became authoritative.

It is a supreme challenge for the popularizer of science to make clear the actual, tortuous history of its great discoveries and the misapprehensions and occasional stubborn refusal by its practitioners to change course. Many, perhaps most, science textbooks for budding scientists tread lightly here. It is enormously easier to present in an appealing way the wisdom distilled from centuries of patient and collective interrogation of Nature than to detail the messy distillation apparatus. The method of science, as stodgy and grumpy as it may seem, is far more important than the findings of science.

2
Science and Hope

> Two men came to a hole in the sky. One asked the other to lift him up . . . But so beautiful was it in heaven that the man who looked in over the edge forgot everything, forgot his companion whom he had promised to help up and simply ran off into all the splendour of heaven.
>
> from an Iglulik Inuit prose poem, early twentieth century, told by Inugpasugjuk to Knud Rasmussen, the Greenlandic arctic explorer

I was a child in a time of hope. I wanted to be a scientist from my earliest school days. The crystallizing moment came when I first caught on that the stars are mighty suns, when it first dawned on me how staggeringly far away they must be to appear as mere points of light in the sky. I'm not sure I even knew the meaning of the word 'science' then, but I wanted somehow to immerse myself in all that grandeur. I was gripped by the splendour of the Universe, transfixed by the prospect of understanding how things really work, of helping to uncover deep mysteries, of exploring new worlds - maybe even literally. It has been my good fortune to have had that dream in part fulfilled. For me, the romance of science remains as appealing and new as it was on that day, more than half a century ago, when I was shown the wonders of the 1939 World's Fair.

Popularizing science - trying to make its methods and findings accessible to non-scientists - then follows naturally and

immediately. *Not* explaining science seems to me perverse. When you're in love, you want to tell the world. This book is a personal statement, reflecting my lifelong love affair with science.

But there's another reason: science is more than a body of knowledge; it is a way of thinking. I have a foreboding of an America in my children's or grandchildren's time - when the United States is a service and information economy; when nearly all the key manufacturing industries have slipped away to other countries; when awesome technological powers are in the hands of a very few, and no one representing the public interest can even grasp the issues; when the people have lost the ability to set their own agendas or knowledgeably question those in authority; when, clutching our crystals and nervously consulting our horoscopes, our critical faculties in decline, unable to distinguish between what feels good and what's true, we slide, almost without noticing, back into superstition and darkness. The dumbing down of America is most evident in the slow decay of substantive content in the enormously influential media, the 30-second sound bites (now down to 10 seconds or less), lowest common denominator programming, credulous presentations on pseudoscience and superstition, but especially a kind of celebration of ignorance. As I write, the number one video cassette rental in America is the movie *Dumb and Dumber*. *Beavis and Butthead* remains popular (and influential) with young TV viewers. The plain lesson is that study and learning - not just of science, but of anything - are avoidable, even undesirable.

We've arranged a global civilization in which most crucial elements - transportation, communications, and all other industries; agriculture, medicine, education, entertainment, protecting the environment; and even the key democratic institution of voting - profoundly depend on science and technology. We have also arranged things so that almost no one understands science and technology. This is a prescription for disaster. We might get away with it for a while, but sooner or later this combustible mixture of ignorance and power is going to blow up in our faces.

A Candle in the Dark is the title of a courageous, largely Biblically based, book by Thomas Ady, published in London in

1656, attacking the witch-hunts then in progress as a scam 'to delude the people'. Any illness or storm, anything out of the ordinary, was popularly attributed to witchcraft. Witches must exist, Ady quoted the 'witchmongers' as arguing, 'else how should these things be, or come to pass?' For much of our history, we were so fearful of the outside world, with its unpredictable dangers, that we gladly embraced anything that promised to soften or explain away the terror. Science is an attempt, largely successful, to understand the world, to get a grip on things, to get hold of ourselves, to steer a safe course. Microbiology and meteorology now explain what only a few centuries ago was considered sufficient cause to burn women to death.

Ady also warned of the danger that 'the Nations [will] perish for lack of knowledge'. Avoidable human misery is more often caused not so much by stupidity as by ignorance, particularly our ignorance about ourselves. I worry that, especially as the millennium edges nearer, pseudoscience and superstition will seem year by year more tempting, the siren song of unreason more sonorous and attractive. Where have we heard it before? Whenever our ethnic or national prejudices are aroused, in times of scarcity, during challenges to national self-esteem or nerve, when we agonize about our diminished cosmic place and purpose, or when fanaticism is bubbling up around us - then, habits of thought familiar from ages past reach for the controls.

The candle flame gutters. Its little pool of light trembles. Darkness gathers. The demons begin to stir.

There is much that science doesn't understand, many mysteries still to be resolved. In a Universe tens of billions of light years across and some ten or fifteen billion years old, this may be the case forever. We are constantly stumbling on surprises. Yet some New Age and religious writers assert that scientists believe that 'what they find is all there is'. Scientists may reject mystic revelations for which there is no evidence except somebody's say-so, but they hardly believe their knowledge of Nature to be complete.

Science is far from a perfect instrument of knowledge. It's just the best we have. In this respect, as in many others, it's like

democracy. Science by itself cannot advocate courses of human action, but it can certainly illuminate the possible consequences of alternative courses of action.

The scientific way of thinking is at once imaginative and disciplined. This is central to its success. Science invites us to let the facts in, even when they don't conform to our preconceptions. It counsels us to carry alternative hypotheses in our heads and see which best fit the facts. It urges on us a delicate balance between no-holds-barred openness to new ideas, however heretical, and the most rigorous sceptical scrutiny of everything - new ideas and established wisdom. This kind of thinking is also an essential tool for a democracy in an age of change.

One of the reasons for its success is that science has built-in, error-correcting machinery at its very heart. Some may consider this an overbroad characterization, but to me every time we exercise self-criticism, every time we test our ideas against the outside world, we are doing science. When we are self-indulgent and uncritical, when we confuse hopes and facts, we slide into pseudoscience and superstition.

Every time a scientific paper presents a bit of data, it's accompanied by an error bar - a quiet but insistent reminder that no knowledge is complete or perfect. It's a calibration of how much we trust what we think we know. If the error bars are small, the accuracy of our empirical knowledge is high; if the error bars are large, then so is the uncertainty in our knowledge. Except in pure mathematics nothing is known for certain (although much is certainly false).

Moreover, scientists are usually careful to characterize the veridical status of their attempts to understand the world - ranging from conjectures and hypotheses, which are highly tentative, all the way up to laws of Nature which are repeatedly and systematically confirmed through many interrogations of how the world works. But even laws of Nature are not absolutely certain. There may be new circumstances never before examined - inside black holes, say, or within the electron, or close to the speed of light - where even our vaunted laws of Nature break down and, however valid they may be in ordinary circumstances, need correction.

Humans may crave absolute certainty; they may aspire to it;

they may pretend, as partisans of certain religions do, to have attained it. But the history of science - by far the most successful claim to knowledge accessible to humans - teaches that the most we can hope for is successive improvement in our understanding, learning from our mistakes, an asymptotic approach to the Universe, but with the proviso that absolute certainty will always elude us.

We will always be mired in error. The most each generation can hope for is to reduce the error bars a little, and to add to the body of data to which error bars apply. The error bar is a pervasive, visible self-assessment of the reliability of our knowledge. You often see error bars in public opinion polls ('an uncertainty of plus or minus three per cent', say). Imagine a society in which every speech in the *Congressional Record,* every television commercial, every sermon had an accompanying error bar or its equivalent.

One of the great commandments of science is, 'Mistrust arguments from authority'. (Scientists, being primates, and thus given to dominance hierarchies, of course do not always follow this commandment.) Too many such arguments have proved too painfully wrong. Authorities must prove their contentions like everybody else. This independence of science, its occasional unwillingness to accept conventional wisdom, makes it dangerous to doctrines less self-critical, or with pretensions to certitude.

Because science carries us toward an understanding of how the world is, rather than how we would wish it to be, its findings may not in all cases be immediately comprehensible or satisfying. It may take a little work to restructure our mindsets. Some of science is very simple. When it gets complicated, that's usually because the world is complicated - or because *we're* complicated. When we shy away from it because it seems too difficult (or because we've been taught so poorly), we surrender the ability to take charge of our future. We are disenfranchised. Our self-confidence erodes.

But when we pass beyond the barrier, when the findings and methods of science get through to us, when we understand and put this knowledge to use, many feel deep satisfaction. This is true for everyone, but especially for children - born with a zest for knowledge, aware that they must live in a future moulded by

science, but so often convinced in their adolescence that science is not for them. I know personally, both from having science explained to me and from my attempts to explain it to others, how gratifying it is when we get it, when obscure terms suddenly take on meaning, when we grasp what all the fuss is about, when deep wonders are revealed.

In its encounter with Nature, science invariably elicits a sense of reverence and awe. The very act of understanding is a celebration of joining, merging, even if on a very modest scale, with the magnificence of the Cosmos. And the cumulative worldwide build-up of knowledge over time converts science into something only a little short of a trans-national, trans-generational meta-mind.

'Spirit' comes from the Latin word 'to breathe'. What we breathe is air, which is certainly matter, however thin. Despite usage to the contrary, there is no necessary implication in the word 'spiritual' that we are talking of anything other than matter (including the matter of which the brain is made), or anything outside the realm of science. On occasion, I will feel free to use the word. Science is not only compatible with spirituality; it is a profound source of spirituality. When we recognize our place in an immensity of light years and in the passage of ages, when we grasp the intricacy, beauty and subtlety of life, then that soaring feeling, that sense of elation and humility combined, is surely spiritual. So are our emotions in the presence of great art or music or literature, or of acts of exemplary selfless courage such as those of Mohandas Gandhi or Martin Luther King Jr. The notion that science and spirituality are somehow mutually exclusive does a disservice to both.

Science may be hard to understand. It may challenge cherished beliefs. When its products are placed at the disposal of politicians or industrialists, it may lead to weapons of mass destruction and grave threats to the environment. But one thing you have to say about it: it delivers the goods.

Not every branch of science can foretell the future - palaeontology can't - but many can and with stunning accuracy. If you want to know when the next eclipse of the Sun will be, you might try magicians or mystics, but you'll do much better with scientists. They

will tell you where on Earth to stand, when you have to be there, and whether it will be a partial eclipse, a total eclipse, or an annular eclipse. They can routinely predict a solar eclipse, to the minute, a millennium in advance. You can go to the witch doctor to lift the spell that causes your pernicious anaemia, or you can take vitamin B_{12}. If you want to save your child from polio, you can pray or you can inoculate. If you're interested in the sex of your unborn child, you can consult plumb-bob danglers all you want (left-right, a boy; forward-back, a girl - or maybe it's the other way around), but they'll be right, on average, only one time in two. If you want real accuracy (here, 99 per cent accuracy), try amniocentesis and sonograms. Try science.

Think of how many religions attempt to validate themselves with prophecy. Think of how many people rely on these prophecies, however vague, however unfulfilled, to support or prop up their beliefs. Yet has there ever been a religion with the prophetic accuracy and reliability of science? There isn't a religion on the planet that doesn't long for a comparable ability - precise, and repeatedly demonstrated before committed sceptics - to foretell future events. No other human institution comes close.

Is this worshipping at the altar of science? Is this replacing one faith by another, equally arbitrary? In my view, not at all. The directly observed success of science is the reason I advocate its use. If something else worked better, I would advocate the something else. Does science insulate itself from philosophical criticism? Does it define itself as having a monopoly on the 'truth'? Think again of that eclipse a thousand years in the future. Compare as many doctrines as you can think of, note what predictions they make of the future, which ones are vague, which ones are precise, and which doctrines - every one of them subject to human fallibility - have error-correcting mechanisms built in. Take account of the fact that not one of them is perfect. Then simply pick the one that in a fair comparison works best (as opposed to feels) best. If different doctrines are superior in quite separate and independent fields, we are of course free to choose several - but not if they contradict one another. Far from being idolatry, this is the means by which we can distinguish the false idols from the real thing.

Again, the reason science works so well is partly that built-in error-correcting machinery. There are no forbidden questions in science, no matters too sensitive or delicate to be probed, no sacred truths. That openness to new ideas, combined with the most rigorous, sceptical scrutiny of all ideas, sifts the wheat from the chaff. It makes no difference how smart, august or beloved you are. You must prove your case in the face of determined, expert criticism. Diversity and debate are valued. Opinions are encouraged to contend - substantively and in depth.

The process of science may sound messy and disorderly. In a way, it is. If you examine science in its everyday aspect, of course you find that scientists run the gamut of human emotion, personality and character. But there's one facet that is really striking to the outsider, and that is the gauntlet of criticism considered acceptable or even desirable. There is much warm and inspired encouragement of apprentice scientists by their mentors. But the poor graduate student at his or her PhD orai exam is subjected to a withering crossfire of questions from the very professors who have the candidate's future in their grasp. Naturally the students are nervous; who wouldn't be? True, they've prepared for it for years. But they understand that at this critical moment, they have to be able to answer searching questions posed by experts. So in preparing to defend their theses, they must practise a very useful habit of thought: they must *anticipate* questions. They have to ask: where in my dissertation is there a weakness that someone else might find? I'd better identify it before they do.

You sit in at contentious scientific meetings. You find university colloquia in which the speaker has hardly gotten thirty seconds into the talk before there are devastating questions and comments from the audience. You examine the conventions in which a written report is submitted to a scientific journal for possible publication, then is conveyed by the editor to anonymous referees whose job it is to ask: did the author do anything stupid? Is there anything in here that is sufficiently interesting to be published? What are the deficiencies of this paper? Have the main results been found by anybody else? Is the argument adequate, or should the paper be resubmitted after the author has actually demonstrated what is here only speculated on? And it's *anonymous:* the

author doesn't know who the critics are. This is the everyday expectation in the scientific community.

Why do we put up with it? Do we like to be criticized? No, no scientist enjoys it. Every scientist feels a proprietary affection for his or her ideas and findings. Even so, you don't reply to critics, wait a minute; this is a really good idea; I'm very fond of it; it's done you no harm; please leave it alone. Instead, the hard but just rule is that if the ideas don't work, you must throw them away. Don't waste neurons on what doesn't work. Devote those neurons to new ideas that better explain the data. The British physicist Michael Faraday warned of the powerful temptation

> to seek for such evidence and appearances as are in the favour of our desires, and to disregard those which oppose them . . . We receive as friendly that which agrees with [us], we resist with dislike that which opposes us; whereas the very reverse is required by every dictate of common sense.

Valid criticism does you a favour.

Some people consider science arrogant - especially when it purports to contradict beliefs of long standing or when it introduces bizarre concepts that seem contradictory to common sense; like an earthquake that rattles our faith in the very ground we're standing on, challenging our accustomed beliefs, shaking the doctrines we have grown to rely upon, can be profoundly disturbing. Nevertheless, I maintain that science is part and parcel humility. Scientists do not seek to impose their needs and wants on Nature, but instead humbly interrogate Nature and take seriously what they find. We are aware that revered scientists have been wrong. We understand human imperfection. We insist on independent and - to the extent possible - quantitative verification of proposed tenets of belief. We are constantly prodding, challenging, seeking contradictions or small, persistent residual errors, proposing alternative explanations, encouraging heresy. We give our highest rewards to those who convincingly disprove established beliefs.

Here's one of many examples: the laws of motion and the inverse square law of gravitation associated with the name of Isaac

Newton are properly considered among the crowning achievements of the human species. Three hundred years later we use Newtonian dynamics to predict those eclipses. Years after launch, billions of miles from Earth (with only tiny corrections from Einstein), the spacecraft beautifully arrives at a predetermined point in the orbit of the target world, just as the world comes ambling by. The accuracy is astonishing. Plainly, Newton knew what he was doing.

But scientists have not been content to leave well enough alone. They have persistently sought chinks in the Newtonian armour. At high speeds and strong gravities, Newtonian physics breaks down. This is one of the great findings of Albert Einstein's Special and General Relativity, and is one of the reasons his memory is so greatly honoured. Newtonian physics is valid over a wide range of conditions including those of everyday life. But in certain circumstances highly unusual for human beings - we are not, after all, in the habit of travelling near light speed - it simply doesn't give the right answer; it does not conform to observations of Nature. Special and General Relativity are indistinguishable from Newtonian physics in its realm of validity, but make very different predictions - predictions in excellent accord with observation - in those other regimes (high speed, strong gravity). Newtonian physics turns out to be an approximation to the truth, good in circumstances with which we are routinely familiar, bad in others. It is a splendid and justly celebrated accomplishment of the human mind, but it has its limitations.

However, in accord with our understanding of human fallibility, heeding the counsel that we may asymptotically approach the truth but will never fully reach it, scientists are today investigating regimes in which General Relativity may break down. For example, General Relativity predicts a startling phenomenon called gravitational waves. They have never been detected directly. But if they do not exist, there is something fundamentally wrong with General Relativity. Pulsars are rapidly rotating neutron stars whose flicker rates can now be measured to fifteen decimal places. Two very dense pulsars in orbit around each other are predicted to radiate copious quantities of gravitational waves, which will in time slightly alter the orbits and rotation periods of the two stars.

Joseph Taylor and Russell Hulse of Princeton University have used this method to test the predictions of General Relativity in a wholly novel way. For all they knew, the results would be inconsistent with General Relativity and they would have overturned one of the chief pillars of modern physics. Not only were they willing to challenge General Relativity, they were widely encouraged to do so. As it turns out, the observations of binary pulsars give a precise verification of the predictions of General Relativity, and for this Taylor and Hulse were co-recipients of the 1993 Nobel Prize in Physics. In diverse ways, many other physicists are testing General Relativity, for example by attempting directly to detect the elusive gravitational waves. They hope to strain the theory to the breaking point and discover whether a regime of Nature exists in which Einstein's great advance in understanding in turn begins to fray.

These efforts will continue as long as there are scientists. General Relativity is certainly an inadequate description of Nature at the quantum level, but even if that were not the case, even if General Relativity were everywhere and forever valid, what better way of convincing ourselves of its validity than a concerted effort to discover its failings and limitations?

This is one of the reasons that the organized religions do not inspire me with confidence. Which leaders of the major faiths acknowledge that their beliefs might be incomplete or erroneous and establish institutes to uncover possible doctrinal deficiencies? Beyond the test of everyday living, who is systematically testing the circumstances in which traditional religious teachings may no longer apply? (It is certainly conceivable that doctrines and ethics that may have worked fairly well in patriarchal or patristic or medieval times might be thoroughly invalid in the very different world we inhabit today.) What sermons even-handedly examine the God hypothesis? What rewards are religious sceptics given by the established religions - or, for that matter, social and economic sceptics by the society in which they swim?

Science, Ann Druyan notes, is forever whispering in our ears, 'Remember, you're very new at this. You might be mistaken. You've been wrong before.' Despite all the talk of humility, show me something comparable in religion. Scripture is said to be

divinely inspired - a phrase with many meanings. But what if it's simply made up by fallible humans? Miracles are attested, but what if they're instead some mix of charlatanry, unfamiliar states of consciousness, misapprehensions of natural phenomena and mental illness? No contemporary religion and no New Age belief seems to me to take sufficient account of the grandeur, magnificence, subtlety and intricacy of the Universe revealed by science. The fact that so little of the findings of modern science is prefigured in Scripture to my mind casts further doubt on its divine inspiration.

But of course I might be wrong.

Read the following two paragraphs - not to understand the science described, but to get a feeling for the author's style of thinking. He is facing anomalies, apparent paradoxes in physics; 'asymmetries' he calls them. What can we learn from them?

> It is known that Maxwell's electrodynamics - as usually understood at the present time - when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena. Take, for example, the reciprocal electrodynamic action of a magnet and a conductor. The observable phenomenon here depends only on the relative motion of the conductor and the magnet, whereas the customary view draws a sharp distinction between the two cases in which either the one or the other of these bodies is in motion. For if the magnet is in motion and the conductor at rest, there arises in the neighbourhood of the magnet an electric field with a certain definite energy, producing a current at the places where parts of the conductor are situated. But if the magnet is stationary and the conductor in motion, no electric field arises in the neighbourhood of the magnet. In the conductor, however, we find an electromotive force, to which in itself there is no corresponding energy, but which gives rise - assuming equality of relative motion in the two cases discussed - to electric currents of the same path and intensity as those produced by the electric forces in the former case.

> Examples of this sort, together with the unsuccessful attempts to discover any motion of the earth relative to the 'ether', suggest that the phenomena of electrodynamics as well as of mechanics possess no properties corresponding to the idea of absolute rest. They suggest rather that, as has already been shown to the first order of small quantities, the same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good.

What is the author trying to tell us here? I'll try to explain the background later in this book. For now, we can perhaps recognize that the language is spare, technical, cautious, clear, and not a jot more complicated than it need be. You would not offhand guess from how it's phrased (or from its unostentatious title, 'On the Electrodynamics of Moving Bodies') that this article represents the crucial arrival of the theory of Special Relativity into the world, the gateway to the triumphant announcement of the equivalence of mass and energy, the deflation of the conceit that our small world occupies some 'privileged reference frame' in the Universe, and in several different ways an epochal event in human history. The opening words of Albert Einstein's 1905 paper are characteristic of the scientific report. It is refreshingly unselfserving, circumspect, understated. Contrast its restrained tone with, say, the products of modern advertising, political speeches, authoritative theological pronouncements - or for that matter the blurb on the cover of this book.

Notice how Einstein's paper begins by trying to make sense of experimental results. Wherever possible, scientists experiment. Which experiments suggest themselves often depends on which theories currently prevail. Scientists are intent on testing those theories to the breaking point. They do not trust what is intuitively obvious. That the Earth is flat was once obvious. That heavy bodies fall faster than light ones was once obvious. That blood-sucking leeches cure most diseases was once obvious. That some people are naturally and by divine decree slaves was once obvious. That there is such a place as the centre of the Universe, and that the Earth sits in that exalted spot was once obvious. That there is

an absolute standard of rest was once obvious. The truth may be puzzling or counterintuitive. It may contradict deeply held beliefs. Experiment is how we get a handle on it.

At a dinner many decades ago, the physicist Robert W. Wood was asked to respond to the toast, 'To physics and metaphysics'. By 'metaphysics', people then meant something like philosophy, or truths you could recognize just by thinking about them. They could also have included pseudoscience. Wood answered along these lines: the physicist has an idea. The more he thinks it through, the more sense it seems to make. He consults the scientific literature. The more he reads, the more promising the idea becomes. Thus prepared, he goes to the laboratory and devises an experiment to test it. The experiment is painstaking. Many possibilities are checked. The accuracy of measurement is refined, the error bars reduced. He lets the chips fall where they may. He is devoted only to what the experiment teaches. At the end of all this work, through careful experimentation, the idea is found to be worthless. So the physicist discards it, frees his mind from the clutter of error, and moves on to something else.*

The difference between physics and metaphysics, Wood concluded as he raised his glass high, is not that the practitioners of one are smarter than the practitioners of the other. The difference is that the metaphysicist has no laboratory.

For me, there are four main reasons for a concerted effort to convey science - on radio and TV, in movies, newspapers, books, computer programs, theme parks and classrooms - to every citizen. In all uses of science, it is insufficient - indeed it is dangerous - to produce only a small, highly competent, well-rewarded priesthood of professionals. Instead, some fundamental understanding of the findings and methods of science must be available on the broadest scale.

*** As the pioneering physicist Benjamin Franklin put it, 'In going on with these experiments, how many pretty systems do we build, which we soon find ourselves obliged to destroy?' At the very least, he thought, the experience sufficed to 'help to make a vain Man humble'.**

- Despite plentiful opportunities for misuse, science can be the golden road out of poverty and backwardness for emerging nations. It makes national economies and the global civilization run. Many nations understand this. It is why so many graduate students in science and engineering at American graduate schools - still the best in the world - are from other countries. The corollary, one that the United States sometimes fails to grasp, is that abandoning science is the road back into poverty and backwardness.
- Science alerts us to the perils introduced by our world-altering technologies, especially to the global environment on which our lives depend. Science provides an essential early warning system.
- Science teaches us about the deepest issues of origins, natures and fates-of our species, of life, of our planet, of the Universe. For the first time in human history we are able to secure a real understanding of some of these matters. Every culture on Earth has addressed such issues and valued their importance. All of us feel goosebumps when we approach these grand questions. In the long run, the greatest gift of science may be in teaching us, in ways no other human endeavour has been able, something about our cosmic context, about where, when and who we are.
- The values of science and the values of democracy are concordant, in many cases indistinguishable. Science and democracy began - in their civilized incarnations - in the same time and place, Greece in the seventh and sixth centuries BC. Science confers power on anyone who takes the trouble to learn it (although too many have been systematically prevented from doing so). Science thrives on, indeed requires, the free exchange of ideas; its values are antithetical to secrecy. Science holds to no special vantage points or privileged positions. Both science and democracy encourage unconventional opinions and vigorous debate. Both demand adequate reason, coherent argument, rigorous standards of evidence and honesty. Science is a way to call the bluff of those who only pretend to knowledge. It is a bulwark against mysticism, against superstition, against religion misapplied to where it has no business

> being. If we're true to its values, it can tell us when we're being lied to. It provides a mid-course correction to our mistakes. The more widespread its language, rules and methods, the better chance we have of preserving what Thomas Jefferson and his colleagues had in mind. But democracy can also be subverted more thoroughly through the products of science than any pre-industrial demagogue ever dreamed.

Finding the occasional straw of truth awash in a great ocean of confusion and bamboozle requires vigilance, dedication and courage. But if we don't practise these tough habits of thought, we cannot hope to solve the truly serious problems that face us and we risk becoming a nation of suckers, a world of suckers, up for grabs by the next charlatan who saunters along.

An extraterrestrial being, newly arrived on earth - scrutinizing what we mainly present to our children on television and radio and in movies, newspapers, magazines, comics and many books- might easily conclude that we are intent on teaching them murder, rape, cruelty, superstition, credulity and consumerism. We keep at it, and through constant repetition many of them finally get it. What kind of society could we create if, instead, we drummed into them science and a sense of hope?