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ARTHUR C. CLARKE

PROFILES OF THE FUTURE

'ONE OF THE TRULY PROPHETIC FIGURES OF THE SPACE AGE...THE COLOSSUS OF SCIENCE FICTION'
NEW YORKER

PROFILES OF THE FUTURE

An Inquiry into the Limits of the Possible

ARTHUR C. CLARKE

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PREFACE TO THE SECOND EDITION

This book originally appeared in 1962, and was based upon essays written during the period 1959-61. Since it was concerned largely with ultimate possibilities, and not with achievements to be expected in the near future, even the remarkable events of the last decade have dated it very little. The chapter *Rocket to the Renaissance,* for example, now appears even more timely than when it was written in 1960, nine years before the first men walked on the moon.

What-has changed – and in ways that no one could possibly have predicted – is our entire attitude towards the future, and especially towards technology as a whole. *Profiles* was one of the first samples of a deluge of books about the future; today, there are societies, foundations, journals devoted to the study of 'futuristics'. The bibliography is getting quite out of hand, and the best way of keeping track of it is through the World Future Society[*], and its excellent magazine *The Futurist.*

Why has the future suddenly become respectable? There is certainly no simple or single explanation. It may be because most educated men have at last begun to understand the imperatives of change, and the urgent need to prepare for the inevitable revolutions in almost every field of human activity. Having lived through several revolutions in half a lifetime makes it easier to accept the possibility that others are still to come.

And yet – this fascination with the future has generated its own antithesis, particularly in the so-called affluent or developed societies. There is a growing disenchantment with 'progress' (however this may be defined) and even a feeling that, in many directions, we have already gone too far.

Some of this attitude, especially among the young, reflects the general malaise of the 1960s – the by-product of traumatic assassinations, disastrous wars, and the other evils of that unhappy decade. Faced with these horrors, it was understandable that many should have decided that it was all the fault of the scientific-technological approach – just as, forty years earlier, their equally sincere and intelligent precursors often blamed everything on capitalism. In each case, there was a lot of truth in the accusations; but it was not the whole truth, and the suggested cures were often worse than the disease.

By the end of the 1960s, the revulsion against the industrial society's excesses had led to a revulsion against reason itself. The drug culture, the 'yippies', the revival of interest in witchcraft, astrology and eccentric religions, the tendency to adopt sandals and beads and to hitch-hike to Katmandu – all these were part of the same pattern. And there was a curious irony in the fact that, at the moment in history when the East was desperately trying to acquire the technology of the West, the West was turning to the East in search of spiritual guidance.*

Hopefully, much good may, in the long run, emerge from this ferment of ideas and philosophies. The extremists on both sides will cancel out; what will be left may be a greater reverence for the organic world, but not an uncritical acceptance of all that is 'natural'. There are many natural things that should be stamped on, hard – and much that is artificial that should be given the utmost encouragement.

I am happy to see that, even in the first edition of this book, I had come out strongly against some of the waste and stupidity of the modern industrial state (see, eg, Chapter 12), though I do not claim to be a premature Ecofreak. At the same time, I cannot pretend that this work will be very much use to those who are struggling to rectify the ills of today's societies. In fact, in some areas it may well be worse than useless, because I am not concerned with the problems of the near future, but with ultimate possibilities. The subtitle 'An Inquiry into the Limits of the Possible' describes exactly what I had in mind. I can well imagine how discouraging it might be, to those struggling to solve today's problems with today's technologies, to read about the wonderful tools we will possess – in the middle of the next century. The other day I had to take a taxi through the teeming slums of Calcutta to deliver a talk largely based on this book. In those circumstances, it was not easy to be optimistic about *any* future.

I would like to express my thanks to all those readers who have made useful comments on the original edition, and particularly to Robert E. Button, COMSAT's Director of Governmental and Foundation Relations, who has used the work as a textbook for his University of Virginia classes for several years – and whose nudgings are partly responsible for this revision.

Some of the ideas in this volume have also been developed in more detail, or in other directions, in two later books *Voices from the Sky* and *Report on Planet Three.*

Arthur C. Clarke
Colombo, Ceylon
1972

INTRODUCTION

It is impossible to predict the future, and all attempts to do so in any detail appear ludicrous within a very few years. This book has a more realistic yet at the same time more ambitious aim. It does not try to describe *the* future, but to define the boundaries within which possible futures must lie. If we regard the ages which stretch ahead of us as an unmapped and unexplored country, what I am attempting to do is to survey its frontiers and to get some idea of its extent. The detailed geography of the interior must remain unknown – until we reach it.

With a few exceptions, I am limiting myself to a single aspect of the future – its technology, not the society that will be based upon it. This is not such a limitation as it may seem, for science will dominate the future even more than it dominates the present. Moreover, it is only in this field that prediction is at all possible; there are some general laws governing scientific extrapolation, as there are not *(pace* Marx) in the case of politics or economics.

I also believe – and hope – that politics and economics will cease to be as important in the future as they have been in the past; the time will come when most of our present controversies on these matters will seem as trivial, or as meaningless, as the theological debates in which the keenest minds of the Middle Ages dissipated their energies. Politics and economics are concerned with power and wealth, neither of which should be the primary, still less the exclusive, concern of full-grown men.

Many writers have, of course, tried to describe the technological wonders of the future, with varying degrees of success. Jules Verne is the classic example – and one never likely to recur, for he was born at an unique moment of time and took full advantage of it. His life (1828–1905) neatly coincided with the rise of applied science; it almost exactly spans the interval between the first locomotive and the first aeroplane. Only one other man has exceeded Verne in the range and accuracy of his predictions: this is the American editor and inventor, Hugo Gernsback (1884-1967). Though his narrative gifts did not match the great Frenchman's, and his fame is not therefore of the same magnitude, Gernsback's indirect influence through his various magazines was comparable to Verne's.

With few exceptions, scientists seem to make rather poor prophets; this is surprising, for imagination is one of the first requirements of a good scientist. Yet, time and again, distinguished astronomers and physicists have made utter fools of themselves by declaring publicly that such-and-such a project was impossible; I shall have pleasure, in the next two chapters, in parading some splendid cautionary examples. The great problem, it seems, is finding a single person who combines sound scientific knowledge – or at least the *feel* for science – with a really flexible imagination. Verne qualified perfectly, and so did Wells, whenever he wished. But Wells, unlike Verne, was also a great literary artist (though he often pretended otherwise) and very sensibly did not allow himself to be shackled by mere facts if they proved inconvenient.

Having evoked the great shades of Verne and Wells, I would now go so far as to claim that *only* readers or writers of science-fiction are really competent to discuss the possibilities of the future. It is no longer necessary, as it was a few years ago, to defend this *genre* from the attacks of ignorant or downright malicious critics; the finest work in the medium stands comparison with all but the very best fiction being published today. But we are not concerned here with the literary qualities of science-fiction – only with its technical content. Over the last thirty years, tens of thousands of stories have explored all the conceivable, and most of the inconceivable, possibilities of the future; there are few things that *can* happen that have not been described somewhere, in books or magazines. A critical – the adjective is important – reading of science-fiction is essential training for anyone wishing to look more than ten years ahead. The facts of the future can hardly be imagined *ab initio* by those who are unfamiliar with the fantasies of the past.

This claim may produce indignation, especially among those second-rate scientists who sometimes make fun of science-fiction (I have never known a first-rate one to do so – and I know several who write it). But the simple fact is that anyone with sufficient imagination to assess the future realistically would, inevitably, be attracted to this form of literature. I do not for a moment suggest that more than 1 per cent of science-fiction readers would be reliable prophets; but I do suggest that almost a hundred per cent of reliable prophets will be science-fiction readers – or writers.

As for my own qualifications for the job, I am content to let the published record speak for itself. Although, like all other propagandists for space-flight, I overestimated the time-scale and underestimated the cost, I am not in the least contrite about this error. Had we known, back in the 1930s, that it was going to cost billions[*] of dollars to develop space vehicles, we should have been completely discouraged; no one could have believed in those days that such sums would ever be available.

The speed with which space-exploration is progressing would have seemed equally unlikely. When Hermann Oberth's pioneering book, *Die Rakete Zu Den*

Planetenraeumen, was reviewed by *Nature* in 1924, that journal remarked, with great daring, 'In these days of unprecedented achievements one cannot venture to suggest that even Herr Oberth's ambitious scheme may not be realized before the human race is extinct.' It has been realized, in large measure, before Professor Oberth is extinct.

I can claim a slightly better record than *Nature's* reviewer. On glancing into my first novel, *Prelude to Space* (written in 1947), I am amused to see that though I scored a direct hit by giving 1959 as the date of the first Moon-rocket, I put manned satellites in 1970 and the landing on the Moon in 1978. This seemed wildly optimitistic to most people at the time, but now demonstrates my innate conservatism. A still better proof of this is provided by the fact that I made no attempt whatsoever, in 1945, to patent the communication satellite. (See Chapter 16.) I couldn't have done so, as it happens; but at least I would have made the effort, had I dreamed that the first experimental models would be operating while I was still in my forties.

In any event, this book is not concerned with time-scales – only with ultimate goals. At the present rate of progress, it is impossible to imagine any technical feat that cannot be achieved, *if* it can be achieved at all, within the next five hundred years. But for the purposes of this enquiry, it is all the same whether the things discussed can be done in ten years or in ten thousand. My only concern is with *what*, not with *when*.

For this reason, many of the ideas developed in this book will be mutually contradictory. To give an example, a really perfect system of communications would have an extremely inhibiting effect on transportation. Less obvious is the converse; if travel became instantaneous, would anyone bother to communicate? The future will have to choose between many competing superlatives; in such cases, I have described each possibility as if the other did not exist.

In a similar manner, some chapters end on an optimistic note, others on a pessimistic. According to the point of view, both unlimited optimism and unlimited pessimism about the future are equally justified. In the final chapter, I have tried to reconcile both.

It has been said that the art of living lies in knowing where to stop, and going a little further. In Chapters 14 and 15 I have attempted to do this by discussing conceptions which are almost certainly not science-fact but science-fantasy. Some people may regard a serious treatment of such ideas as invisibility and the Fourth Dimension as a waste of time, but in this context it is fully justified. It is as important to discover what cannot be done as what can be done; and it is sometimes considerably more amusing.

While writing this introduction, I came across a review of a somewhat pedestrian Russian book about the twenty-first century. The distinguished British scientist writing the review found the work extremely reasonable and the author’s extrapolations quite convincing.

I hope this charge will not be levelled against me. If this book seems completely reasonable and all *my* extrapolations convincing, I shall not have succeeded in looking very far ahead; for the one fact about the Future of which we can be certain is that it will be utterly fantastic.

ONE

HAZARDS OF PROPHECY: THE FAILURE OF NERVE

Before one attempts to set up in business as a prophet, it is instructive to see what success others have made of this dangerous occupation – and it is even more instructive to see where they have failed.

With monotonous regularity, apparently competent men have laid down the law about what is technically possible or impossible – and have been proved utterly wrong, sometimes while the ink was scarcely dry from their pens. On careful analysis, it appears that these debacles fall into two classes, which I will call Failures of Nerve and Failures of Imagination.

The Failure of Nerve seems to be the more common; it occurs when *even given all the relevant facts* the would-be prophet cannot see that they point to an inescapable conclusion. Some of these failures are so ludicrous as to be almost unbelievable, and would form an interesting subject for psychological analysis. 'They said it couldn't be done' is a phrase that occurs throughout the history of invention; I do not know if anyone has ever looked into the reasons *why* 'they' said so, often with quite unnecessary vehemence.

It is now impossible for us to recall the mental climate which existed when the first locomotives were being built, and critics gravely asserted that suffocation lay in wait for anyone who reached the awful speed of thirty miles an hour. It is equally difficult to believe that, only eighty years ago, the idea of the domestic electric light was pooh-poohed by all the 'experts' – with the exception of a 31-year-old American inventor named Thomas Alva Edison. When gas securities nose-dived in 1878 because Edison (already a formidable figure, with the phonograph and the carbon microphone to his credit) announced that he was working on the incandescent lamp, the British Parliament set up a committee to look into the matter. (Westminster can beat Washington hands down at this game.)

The distinguished witnesses reported, to the relief of the gas companies, that Edison's ideas were 'good enough for our transatlantic friends … but unworthy of the attention of practical or scientific men'. And Sir William Preece, Engineer-in-Chief of the British Post Office, roundly declared that ‘subdivision of the electric light is an absolute *ignis fatuus*’. One feels that the fatuousness was not in the *ignis.*

The scientific absurdity being pilloried, be it noted, is not some wild-and-woolly dream like perpetual motion, but the humble little electric light bulb, which three generations of men have taken for granted, except when it burns out and leaves them in the dark. Yet although in this matter Edison saw far beyond his contemporaries, he too in later life was guilty of the same shortsightedness that afflicted Preece and Co, for he opposed the introduction of alternating current.

The most famous, and perhaps the most instructive, Failures of Nerve have occurred in the fields of aero- and astronautics. At the beginning of the twentieth century, scientists were almost unanimous in declaring that heavier-than-air flight was impossible, and that anyone who attempted to build aeroplanes was a fool. The great American astronomer, Simon Newcomb, wrote a celebrated essay which concluded:

> ‘The demonstration that no possible combination of known substances, known forms of machinery and known forms of force, can be united in a practical machine by which men shall fly long distances through the air, seems to the writer as complete as it is possible for the demonstration of any physical fact to be.’

Oddly enough, Newcomb was sufficiently broadminded to admit that some wholly new discovery – he mentioned the neutralization of gravity – might make flight practical. One cannot, therefore, accuse him of lacking imagination; his error was in attempting to marshal the facts of aerodynamics, when he did not understand that science. His failure of nerve lay in not realizing that the means of flight were already at hand.

For Newcomb’s article received wide publicity at just about the time that the Wright Brothers, not having a suitable anti-gravity device in their bicycle shop, were mounting a petrol engine on wings. When news of their success reached the astronomer, he was only momentarily taken aback. Flying machines *might* be a marginal possibility, he conceded – but they were certainly of no practical importance, for it was quite out of the question that they could carry the extra weight of a passenger as well as that of a pilot…

Such refusal to face facts which now seem obvious has continued throughout the history of aviation. Let me quote another astronomer, William H. Pickering, straightening out the uninformed public a few years *after* the first aeroplanes had started to fly.

> ‘The popular mind often pictures gigantic flying machines speeding across the Atlantic and carrying innumerable passengers in a way analogous to our modern steamships… It seems safe to say that such ideas must be wholly visionary, and even if a machine could get across with one or two passengers the expense would be prohibitive to any but the capitalist who could own his own yacht. Another popular fallacy is to expect enormous speed to be obtained. It must be remembered that the resistance of the air increases as the square of the speed and the work as the cube … If with 30 hp we can now attain a speed of 40 mph, then in order to reach a speed of 100 mph we must use a motor capable of 470 hp … it is clear that with our present devices there is no hope of competing for racing speed with either our locomotives or our automobiles.’

It so happens that most of his fellow-astronomers considered Pickering far too imaginative; he was prone to see vegetation – and even evidence for insect life – on the Moon. I am glad to say that by the time he died in 1938 at the ripe age of 80, Professor Pickering had seen aeroplanes travelling at 400 mph, and carrying considerably more than ‘one or two’ passengers.

Closer to the present, the opening of the Space Age has produced a mass vindication (and refutation) of prophecies on a scale and at a speed never before witnessed. Having taken some part in this myself, and being no more immune than the next man to the pleasures of saying ‘I told you so’, I would like to recall a few of the statements about space-flight that have been made by prominent scientists in the past. It is necessary for *someone* to do this, and to jog the remarkably selective memories of the pessimists. The speed with which those who once declaimed ‘It’s impossible’ can switch to ‘I said it could be done all the time’ is really astounding.

As far as the general public is concerned, the idea of spaceflight as a serious possibility first appeared on the horizon in the 1920s, largely as a result of newspaper reports of the work of the American, Robert Goddard, and the Rumanian, Hermann Oberth (the much earlier studies of Tsiolkovsky in Russia then being almost unknown outside his own country.) When the ideas of Goddard and Oberth, usually distorted by the press, filtered through to the scientific world, they were received with hoots of derision. For a sample of the kind of criticism the pioneers of astronautics had to face, I present this masterpiece from a paper published by one Professor A. W. Bickerton in 1926. It should be read carefully, for as an example of arrogant ignorance it would be very hard to beat.

> ‘This foolish idea of shooting at the moon is an example of the absurd length to which vicious specialization will carry scientists working in thought-tight compartments. Let us critically examine the proposal. For a projectile entirely to escape the gravitation of the earth, it needs a velocity of 7 miles a second. The thermal energy of a gramme at this speed is 15,180 calories … The energy of our most violent explosive – nitroglycerine – is less than 1,500 calories per gramme. Consequently, even had the explosive nothing to carry, it has only one-tenth of the energy necessary to escape the earth … Hence the proposition appears to be basically impossible…’

Indignant readers in the Colombo Public Library pointed angrily to the SILENCE notices when I discovered this little gem. It is worth examining it in some detail to see just where ‘vicious specialization’, if one may coin a phrase, led the professor so badly astray.

His first error lies in the sentence: ‘The energy of our most violent explosive – nitroglycerine …’ One would have thought it obvious that *energy,* not violence, is what we want from a rocket fuel; and as a matter of fact nitroglycerine and similar explosives contain much less energy, weight for weight, than such mixtures as kerosene and liquid oxygen. This had been carefully pointed out by Tsiolkovsky and Goddard years before.

Bickerton’s second error is much more culpable; without mincing words, it is due to sheer stupidity. What of it, if nitroglycerine has only a tenth of the energy necessary to escape from the Earth? That merely means that you have to use at least ten pounds of nitroglycerine to launch a single pound of payload.[*]

For the fuel itself has not got to escape from Earth; it can all be burned quite close to our planet, and as long as it imparts its energy to the payload, this is all that matters. When Lunik II lifted thirty-three years after Professor Bickerton said it was impossible, most of its several hundred tons of kerosene and liquid oxygen never got very far from Russia … but the half-ton payload reached the Mare Imbrium.

As a comment to the above, I might add that Professor Bickerton, who was an active popularizer of science, numbered among his published books one with the title *Perils of a Pioneer*. Of the perils that all pioneers must face, few are more disheartening than the Bickertons.

Right through the 1930s and 1940s, eminent scientists continued to deride the rocket pioneers – when they bothered to notice them at all. Anyone who has access to a good college library can find, preserved for posterity in the dignified pages of the January 1941 *Philosophical Magazine*, an example specially interesting owing to the eminence of its author.

It is a paper by the distinguished Canadian astronomer, Professor J. W. Campbell, of the University of Alberta, entitled *Rocket Flight to the Moon.* Opening with a quotation from a 1938 Edmonton paper to the effect that 'rocket flight to the Moon now seems less remote than television appeared a hundred years ago', the professor then looks into the subject mathematically. After several pages of analysis, he arrives at the conclusion that it would require *a million tons* of take-off weight to carry *one pound* of payload on the round trip.

The correct figure, for today's primitive fuels and technologies, is very roughly one ton per pound – a depressing ratio, but hardly as bad as that calculated by the professor. Yet his mathematics was impeccable; so what went wrong?

Merely his initial assumptions, which were hopelessly unrealistic. He chose a path for the rocket which was fantastically extravagant in energy, and he assumed the use of an acceleration so low that most of the fuel would be wasted at low altitudes, fighting the earth's gravitational field. It was as if he had calculated the performance of an automobile when the brakes were on. No wonder that he concluded: 'While it is always dangerous to make a negative prediction, it would appear that the statement that rocket flight to the moon does not seem so remote as television did less than one hundred years ago is over optimistic.' I am sure that when the *Philosophical Magazine* subscribers read those words, back in 1941, many of them thought 'Well, *that* should put those crazy rocket-men in their place!'

Yet the correct results had been published by Tsiolkovsky, Oberth and Goddard years before; though the work of the first two would have been very hard to consult at the time, Goddard's paper *A Method of Reaching Extreme Altitudes* was already a classic and had been issued by that scarcely obscure body, the Smithsonian Institution. If Professor Campbell had only consulted it (or indeed *any* competent writer on the subject – there were some, even in 1914) he would not have misled his readers and himself. And he would not have had to put up with a rather sarcastic analysis of his paper by myself in the September 1948 issue of the *Journal of the British Interplanetary Society*, which caused him some pain on its appearance. If he happens to read these words, I apologize for my rudeness; but not for my criticism.

The lesson to be learned from these examples is one that can never be repeated too often, and is one that is seldom understood by laymen – who have an almost superstitious awe of mathematics. But mathematics is only a tool, though an immensely powerful one. No equations, however impressive and complex, can arrive at the truth if the initial assumptions are incorrect. It is really quite amazing by what margins competent but conservative scientists and engineers can miss the mark, when they start with the preconceived idea that what they are investigating is impossible. When this happens, the most well-informed men become blinded by their prejudices and are unable to see what lies directly ahead of them. What is even more incredible, they refuse to learn from experience; they will continue to make the same mistake over and over again.

Some of my best friends are astronomers, and I am sorry to keep throwing stones at them – but they do seem to have an appalling record as prophets. If you still doubt this, let me tell a story so ironic that you might well accuse me of making it up. But I am not that much of a cynic; the facts are on file for anyone to check.

Back in the dark ages of 1935, the founder of the British Interplanetary Society, P. E. Cleator, was rash enough to write the first book on astronautics published in England. His *Rockets Through Space* gave an (incidentally highly entertaining) account of the experiments that had been carried out by the German and American rocket pioneers, and their plans for such commonplaces of today as giant multi-stage boosters and satellites. Rather surprisingly, the staid scientific journal *Nature* reviewed the book in its issue for March 14th, 1936, and summed up as follows:

> 'It must be said at once that the whole procedure sketched in the present volume presents difficulties of so fundamental a nature that we are forced to dismiss the notion as essentially impracticable, in spite of the author's insistent appeal to put aside prejudice and to recollect the supposed impossibility of heavier-than-air flight before it was actually accomplished. An analogy such as this may be misleading, and we believe it to be so in this case. …'

Well, the whole world now knows just how misleading this analogy was, though the reviewer, identified only by the unusual initials 'R.v.d.R.W.' was of course fully entitled to his opinion.

Just twenty years later – *after* President Eisenhower had announced the United States satellite programme – a new Astronomer Royal arrived in England to take up his appointment. The Press asked him to give his views on space-flight, and after two decades Dr Richard van der Riet Woolley had seen no reason to change his mind. 'Space travel,' he snorted, 'is utter bilge.'

The newspapers did not allow him to forget this when Sputnik I went up the very next year. Later – irony piled upon irony – Dr Woolley became, by virtue of his position as Astronomer Royal, a leading member of the committee advising the British government on space-research. The feelings of those who have been trying, for a generation, to get the United Kingdom interested in space can well be imagined.*

Even those who suggested that rockets might be used for more modest, though much more reprehensible, purposes were overruled by the scientific authorities – except in Germany and Russia.

When the existence of the 200-mile-range V2 was disclosed to an astonished world, there was considerable speculation about intercontinental missiles. This was firmly squashed by Dr Vannevar Bush, the civilian general of the US scientific war effort, in evidence before a Senate Committee on 3rd December, 1945. Listen:

> ‘There has been a great deal said about a 3,000 mile high-angle rocket. In my opinion such a thing is impossible for many years. The people who have been writing these things that annoy me, have been talking about a 3,000 mile high-angle rocket shot from one continent to another, carrying an atomic bomb and so directed as to be a precise weapon which would land exactly on a certain target, such as a city.
>
> ‘I say, technically, I don’t think anyone in the world knows how to do such a thing, and I feel confident that it will not be done for a very long period of time to come. … I think we can leave that out of our thinking. I wish the American public would leave that out of their thinking.’

A few months earlier (in May 1945) Prime Minister Churchill’s scientific adviser Lord Cherwell had expressed similar views in a House of Lords debate. This was only to be expected, for Cherwell was an extremely conservative and opinionated scientist who had advised the government that the V2 itself was only a propaganda rumour.*

In the May 1945 debate on defence, Lord Cherwell impressed his peers by a dazzling display of mental arithmetic from which he correctly concluded that a very long-range rocket must consist of more than 90 per cent fuel, and thus would have a negligible payload. The conclusion he let his listeners draw from this was that such a device would be wholly impracticable.

That was true enough in the spring of 1945, but it was no longer true in the summer. One astonishing feature of the House of Lords debate is the casual way in which much-too-well-informed peers used the phrase ‘atomic bomb’, at a time when this was the best-kept secret of the war. (The Alamagordo test was still two months in the future.) Security must have been horrified, and Lord Cherwell – who of course knew all about the Manhattan Project – was quite justified in telling his inquisitive colleagues not to believe everything that they heard, even though in this case it happened to be perfectly true.

When Dr Bush spoke to the Senate Committee in December of the same year, the only important secret about the atomic bomb was that it weighed five tons. Anyone could then work out in his head, as Lord Cherwell had done, that a rocket to deliver it across intercontinental ranges would have to weigh about 200 tons – as against the mere fourteen tons of the then awe-inspiring V2.

The outcome was the greatest Failure of Nerve in all history, which changed the future of the world – indeed, of many worlds. Faced with the same facts and the same calculations, American and Russian technology took two separate roads. The Pentagon – accountable to the taxpayer – virtually abandoned long-range rockets for almost half a decade, until the development of thermonuclear bombs made it possible to build warheads five times lighter, yet fifty times more powerful, than the amusing firecracker that was dropped on Hiroshima.

The Russians had no such inhibitions. Faced with the need for a 200-ton rocket, they went right ahead and built it. By the time it was perfected, it was no longer required for military purposes, for Soviet physicists had by-passed the United States' billion-dollar tritium bomb *cul-de-sac* and gone straight to the far cheaper lithium bomb. Having backed the wrong horse in rocketry, the Russians then entered it for a much more important event – and won the race into Space.

Of the many lessons to be drawn from this slice of recent history, the one that I wish to emphasize is this. Anything that is theoretically possible will be achieved in practice, no matter what the technical difficulties, if it is desired greatly enough. It is no argument against any project to say: 'The idea's fantastic!' Most of the things that have happened in the last fifty years have been fantastic, and it is only by assuming that they will continue to be so that we have any hope of anticipating the future.

To do this – to avoid that Failure of Nerve for which history exacts so merciless a penalty – we must have the courage to follow all technical extrapolations to their logical conclusion. Yet even this is not enough, as I shall now demonstrate. To predict the future we need logic; but we also need faith and imagination which can sometimes defy logic itself.

TWO

HAZARDS OF PROPHECY: THE FAILURE OF IMAGINATION

In the last chapter, I suggested that many of the negative statements about scientific possibilities, and the gross failures of past prophets to predict what lay immediately ahead of them, could be described as ‘Failures of Nerve’. All the basic facts of aeronautics were available – in the writings of Cayley, Stringfellow, Chanute and others – when Simon Newcomb ‘proved’ that flight was impossible. He simply lacked the courage to face those facts. All the fundamental equations and principles of space-travel had been worked out by Tsiolkovsky, Goddard and Oberth for years – often decades – when distinguished scientists were making fun of would-be astronauts. Here again, the failure to appreciate the facts was not so much intellectual as moral. The critics did not have the courage that their scientific convictions should have given them; they could not believe the truth even when it had been spelled out before their eyes, in their own language of mathematics. We all know this type of cowardice, because at some time or other we all exhibit it.

The second kind of prophetic failure is less blameworthy, and more interesting. It arises when all the available facts are appreciated *and* marshalled correctly – but when the really vital facts are still undiscovered, and the possibility of their existence is not admitted.

A famous example of this is provided by the philosopher, Auguste Comte, who in his *Cours de Philosophie Positive* (1835) attempted to define the limits within which scientific knowledge must lie. In his chapter on astronomy (Book 2, Chapter 1) he wrote these words concerning the heavenly bodies:

> ‘We see how we may determine their forms, their distances, their bulk, their motions, but we can never know anything of their chemical or mineralogical structure; and much less, that of organized beings living on their surface … We must keep carefully apart the idea of the solar system and that of the universe, and be always assured that our only true interest is in the former. Within this boundary alone is astronomy the supreme and positive science

> that we have determined it to be … the stars serve us scientifically only as providing positions with which we may compare the interior movements of our system.’

In other words, Comte decided that the stars could never be more than celestial reference points, of no intrinsic concern to the astronomer. Only in the case of the planets could we hope for any definite knowledge, and even that knowledge would be limited to geometry and dynamics. Comte would probably have decided that such a science as ‘astrophysics’ was *a priori* impossible.

Yet within half a century of his death, almost the whole of astronomy *was* astrophysics, and very few professional astronomers had much interest in the planets. Comte’s assertion had been utterly refuted by the invention of the spectroscope, which not only revealed the ‘chemical structure’ of the heavenly bodies but has now told us far more about the distant stars than we know of our planetary neighbours.

Comte cannot be blamed for not imagining the spectroscope; *no one* could have imagined it, or the still more sophisticated instruments that have now joined it in the astronomer’s armoury. But he provides a warning that should always be borne in mind; even things that are undoubtedly impossible with existing or foreseeable techniques may prove to be easy as a result of new scientific breakthroughs. From their very nature, these breakthroughs can never be anticipated; but they have enabled us to by-pass so many insuperable obstacles in the past that no picture of the future can hope to be valid if it ignores them.

Another celebrated failure of imagination was that persisted in by Lord Rutherford, who more than any other man laid bare the internal structure of the atom. Rutherford frequently made fun of those sensation-mongers who predicted that we would one day be able to harness the energy locked up in matter. Yet only five years after his death in 1937, the first chain reaction was started in Chicago. What Rutherford, for all his wonderful insight, had failed to take into account was that a nuclear reaction might be discovered that would release more energy than that required to start it. To liberate the energy of matter, what was wanted was a nuclear ‘fire’ analogous to chemical combustion, and the fission of uranium provided this. Once that was discovered, the harnessing of atomic energy was inevitable, though without the pressures of war it might well have taken the better part of a century.

The example of Lord Rutherford demonstrates that it is not the man who knows most about a subject, and is the acknowledged master of his field, who can give the most reliable pointers to its future. Too great a burden of knowledge can clog the wheels of imagination; I have tried to embody this fact of observation in Clarke's Law, which may be formulated as follows:

> 'When a distinguished but elderly scientist states that something is possible, he is almost certainly right. When he states that something is impossible, he is very probably wrong.'

Perhaps the adjective 'elderly' requires definition. In physics, mathematics and astronautics it means over thirty; in the other disciplines, senile decay is sometimes postponed to the forties. There are, of course, glorious exceptions; but as every researcher just out of college knows, scientists of over fifty are good for nothing but board meetings, and should at all costs be kept out of the laboratory.

Too much imagination is much rarer than too little; when it occurs, it usually involves its unfortunate possessor in frustration and failure – unless he is sensible enough merely to write about his ideas, and not to attempt their realization. In the first category we find all the science-fiction authors, historians of the future, creators of Utopias – and the two Bacons, Roger and Francis.

Friar Roger (*c* 1214-1292) imagined optical instruments and mechanically propelled boats and flying machines – devices far beyond the existing or even foreseeable technology of his time. It is hard to believe that these words were written in the thirteenth century:

> 'Instruments may be made by which the largest ships, with only one man guiding them, will be carried with greater velocity than if they were full of sailors. Chariots may be constructed that will move with incredible rapidity without the help of animals. Instruments of flying may be formed in which a man, sitting at his ease and meditating in any subject, may beat the air with his artificial wings after the manner of birds … as also machines which will enable men to walk at the bottom of the seas …'

This passage is a triumph of imagination over hard fact. Everything in it has come true, yet at the time it was written it was more an act of faith than of logic. It is probable that all long-range prediction, if it is to be accurate, must be of this nature. The real future is not logically foreseeable.

A splendid example of a man whose imagination ran ahead of his age was the English mathematician, Charles Babbage (1792-1871). As long ago as 1819, Babbage had worked out the principles underlying automatic computing machines. He realized that all mathematical calculations could be broken down into a series of step-by-step operations that could, in theory, be carried out by a machine. With the aid of a government grant which eventually totalled £17,000 – a very substantial sum of money in the 1820s – he started to build his ‘analytical engine’.

Though he devoted the rest of his life, and much of his private fortune, to the project, Babbage was unable to complete the machine. What defeated him was the fact that precision engineering of the standard he needed to build his cogs and gears simply did not exist at the time. By his efforts he helped to create the machine tool industry – so that in the long run the government got back very much more than its £17,000 – and today it would be a perfectly straightforward matter to complete Babbage’s computer, which now stands as one of the most fascinating exhibits in the London Science Museum. In his own lifetime, however, Babbage was only able to demonstrate the operation of a relatively small portion of the complete machine. A dozen years after his death, his biographer wrote: ‘This extraordinary monument of theoretical genius accordingly remains, and doubtless will for ever remain, a theoretical possibility.’

There is not much left of that ‘doubtless’ today. At this moment there are thousands of computers working on the principles that Babbage clearly outlined more than a century ago – but with a range and a speed of which he could never have dreamed. For what makes the case of Charles Babbage so interesting, and so pathetic, is that he was not one but *two* technological revolutions ahead of his time. Had the precision tool industry existed in 1820, he could have built his ‘analytical engine’ and it would have worked, much faster than a human computer, but very slowly by the standards of today. For it would have been geared – literally – to the speed with which cogs and shafts and cams and ratchets can operate.

Automatic calculating machines could not come into their own until electronics made possible speeds of operation thousands and millions of times swifter than could be achieved with purely mechanical devices. This level of technology was reached in the 1940s, and Babbage was then promptly vindicated. His failure was not one of imagination: it lay in being born a hundred years too soon.

One can only prepare for the unpredictable by trying to keep an open and unprejudiced mind – a feat which is extremely difficult to achieve, even with the best will in the world. Indeed, a completely open mind would be an empty one, and freedom from all prejudices and preconceptions is an unattainable ideal. Yet there is one form of mental exercise that can provide good basic training for would-be prophets: anyone who wishes to cope with the future should travel back in imagination a single lifetime – say to 1900 – and ask himself just how much of today's technology would be, not merely incredible, but *incomprehensible* to the keenest scientific brains of that time.

1900 is a good round date to choose, because it was just about then that all hell started to break loose in science. As J. B. Conant has put it:

> 'Somewhere about 1900 science took a *totally* unexpected turn. There had previously been several revolutionary theories and more than one epoch-making discovery in the history of science, but what occurred between 1900 and, say 1930 was something different; it was a failure of a general prediction about what might be confidently expected from experimentation.'

P. W. Bridgman has put it even more strongly:

> 'The physicist has passed through an intellectual crisis forced by the discovery of experimental facts of a sort which he had not previously envisaged, and which he would not even have thought possible.'

The collapse of 'classical' science actually began with Rontgen's discovery of X-rays in 1895; here was the first clear indication, in a form that everyone could appreciate, that the common-sense picture of the universe was not sensible after all. X-rays – the very name reflects the bafflement of scientist and layman alike – could travel through solid matter, like light through a sheet of glass. No one had ever imagined or predicted such a thing; that one would be able to peer into the interior of the human body – and thereby revolutionize medicine and surgery – was something that the most daring prophet had never suggested.

The discovery of X-rays was the first great breakthrough into realms where no human mind had ever ventured before. Yet it gave scarcely a hint of still more astonishing developments to come – radioactivity, the internal structure of the atom, Relativity, the Quantum Theory, the Uncertainty Principle …

As a result of this, the inventions and technical devices of our modern world can be divided into two sharply defined classes. On the one hand there are those machines whose working would have been fully understood by any of the great thinkers of the past; on the other, there are those that would be utterly baffling to the finest minds of antiquity. And not merely of antiquity; there are devices now coming into use that might well have driven Edison or Marconi insane had they tried to fathom their operation.

Let me give some examples to emphasize this point. If you showed a modern diesel engine, an automobile, a steam turbine, or a helicopter to Benjamin

Franklin, Galileo, Leonardo da Vinci, and Archimedes – a list spanning two thousand years of time – not one of them would have any difficulty in understanding how these machines worked. Leonardo, in fact, would recognize several from his notebooks. All four men would be astonished at the materials and the workmanship, which would have seemed magical in its precision, but once they had got over that surprise they would feel quite at home – as long as they did not delve too deeply into the auxiliary control and electrical systems.

But now suppose they were confronted by a television set, an electronic computer, a nuclear reactor, a radar installation. Quite apart from the complexity of these devices, the individual elements of which they are composed would be incomprehensible to any man born before this century. Whatever his degree of education or intelligence, he would not possess the mental framework that could accommodate electron-beams, transistors, atomic fission, waveguides and cathode-ray tubes.

The difficulty, let me repeat, is not one of complexity; some of the simplest modern devices would be the most difficult to explain. A particularly good example is given by the atomic bomb (at least, the early models). What could be simpler than banging two lumps of metal together? Yet how could one explain to Archimedes that the result could be more devastation than that produced by all the wars between the Trojans and the Greeks?

Suppose you went to any scientist up to the late nineteenth century and told him: 'Here are two pieces of substance called Uranium 235. If you hold them apart, nothing will happen. But if you bring them together suddenly, you will liberate as much energy as you could obtain from burning ten thousand tons of coal.' No matter how far-sighted and imaginative he might be, your pre-twentieth-century scientist would have said: 'What utter nonsense! That's magic, not science. Such things can't happen in the real world.' Around 1890, when the foundations of physics and thermodynamics had (it seemed) been securely laid, he could have told you exactly why it was nonsense.

'Energy cannot be created out of nowhere,' he might have said. 'It has to come from chemical reactions, electrical batteries, coiled springs, compressed gas, spinning flywheels, or some other clearly defined source. All such sources are ruled out in this case – and even if they were not, the energy output you mention is absurd. Why, it is more than a *million* times that available from the most powerful chemical reaction!'

The fascinating thing about this particular example is that, even when the existence of atomic energy was fully appreciated – say right up to 1940 – almost all scientists would still have laughed at the idea of liberating it by bringing pieces of metal together. Those who believed that the energy of the nucleus ever could be released almost certainly pictured complicated electrical devices – ‘atom smashers’ and so forth – doing the job. (In the long run, this will probably be the case; it seems that we will need such machines to fuse hydrogen nuclei on the industrial scale. But once again, who knows?)

The wholly unexpected discovery of uranium fission in 1938 made possible such absurdly simple (in principle, if not in practice) devices as the atomic bomb and the nuclear chain reactor. No scientists could ever have predicted them; if he had, all his colleagues would have laughed at him.

It is highly instructive, and stimulating to the imagination, to make a list of the inventions and discoveries that have been anticipated – and those that have not. Here is my attempt to do so.

All the items on the left have already been achieved or discovered, and all have an element of the unexpected or the downright astonishing about them. To the best of my knowledge, not one was foreseen very much in advance of the moment of revelation.

On the right, however, are concepts that have been around for hundreds or thousands of years. Some have been achieved; others will be achieved; others may be impossible. But which?

The unexpected	***The expected***
X-rays	Automobiles
Nuclear Energy	Flying machines
Radio, TV	Steam engines
Electronics	Submarines
Photography	Spaceships
Sound-recording	Telephones
Quantum mechanics	Robots
Relativity	Death-rays
Transistors	Transmutation
Masers; Lasers	Artificial life
Superconductors; superfluids	Immortality
Atomic clocks; Mössbauer Effect	Invisibility
Determining composition of celestial bodies	Levitation
Dating the past (Carbon 14, etc)	Teleportation
Detecting invisible planets	Communication with dead

The Ionosphere; van Allen Belts	Observing the past, the future
Telepathy	

The right-hand list is deliberately provocative; it includes sheer fantasy as well as serious scientific speculation. But the only way of discovering the limits of the possible is to venture a little way past them into the impossible.[*]

As three laws were good enough for Newton, I have modestly decided to stop there. In the chapters that follow, this is exactly what I hope to do; yet I am very much afraid that from time to time I too will exhibit Failure of Imagination – if not Failure of Nerve. For as I glance down the left-hand column I am aware of a few items which, only ten years ago, I would have thought were impossible …

THREE

THE FUTURE OF TRANSPORT

Most of the energy expended in the history of the world has been used to move things from one place to another. For thousands upon thousands of years, the rate of movement was very low – less than 2 or 3 mph, the pace of a walking man. Even the domestication of the horse did not raise this figure appreciably, for though a racehorse can exceed forty miles an hour for very short periods, the main use of the horse has always been as a slow-moving beast of burden and a hauler of vehicles. The fastest of these – the stage-coaches immortalized by Dickens – could seldom have travelled at more than ten miles an hour on the roads that existed before the nineteenth century.

For almost the whole of human history and prehistory, therefore, men's thoughts and their ways of life have been restricted to the tiny band of the speed spectrum between one and ten miles an hour. Yet within the span of a few generations, the velocity of travel has been multiplied a hundredfold; indeed, there are good grounds for thinking that the acceleration that has taken place round the mid-twentieth century will never again be matched.

Speed, however, is not the only criterion of transport, and there are times when it is positively undesirable – especially if it conflicts with safety, comfort or economics. As far as transportation at ground level is concerned, we may well have reached (if not passed) the practical limit of speed, and future improvements must lie in other directions. No one wants to travel down Oxford Street at the velocity of sound, but many Londoners would be very happy if they could always be sure of doing so at the speed of a stage-coach.

There are many ways of classifying methods of transportation, the most obvious being by media – land, sea, air or space. But these divisions are becoming more and more arbitrary, now that there are vehicles that operate equally efficiently in two or more of them. For the present purpose, a scheme based on distance is the most convenient; on our 8,000 mile diameter planet, only four ranges are involved.

	Range – Miles	Designation	Mode	
			Passenger	Freight
1.	1–10	Very short (Local, urban)	Foot. Horse. Bicycle. *Scooter*. Car. Bus. Subway. Conveyor.	*Truck*. Pipeline. Conveyor.
2.	10–100	Short (Suburban, local)	*Car*. Bus. Rail. Boat. Conveyor.	*Truck*. Pipeline. Rail.
3.	100–1,000	Medium (Continental)	Car. Bus. *Rail*. Boat. Aeroplane. GEM. VTOL.	Truck. *Rail*. Aeroplane. GEM. VTOL.
4.	1,000–10,000	Long (Inter-continental)	Rail. *Aeroplane*. Ship. GEM. Ramjet. Rocket.	Rail. *Ship*. Aircraft. GEM. Submarine.

GEM = Ground Effect Machine
VTOL = Vertical Take-off and Landing aircraft

In the first category – very short ranges – only police, doctors and firemen have any need to travel at over fifty miles an hour, or any right to inflict such speeds on the community. For this range, I would suggest that the ideal means of individual transportation is the motor-scooter or the very small bubble-car. Indeed, I would like to be thoroughly reactionary and suggest that the almost obsolete habit of walking still has much to recommend it in terms of physical health, mental well-being – and frequently speed, as anyone who has ever been caught in a big city traffic jam will admit. Perhaps the only excuse for *not* walking, when short distances are involved, is the weather, and even this excuse will eventually vanish. In the cities, of course, the weather will be fully controlled before another century has passed; and outside them, even if we cannot control it, we will certainly be able to predict it and make plans accordingly.

While we are in this backward-looking mood, let me make an even more startling suggestion. The best personal transport vehicle Man has ever possessed – where only short ranges are concerned and the weather is good – is the horse. It is self-steering, self-reproducing, never goes out of style – and only a double-decker bus gives a comparable view of the scenery. I admit that there are some disadvantages; horses are expensive to maintain, prone to embarrassing behaviour and are not really very bright. But these are not *fundamental* limitations, for one day we will be able to increase the intelligences of our domestic animals, or evolve wholly new ones with much higher IQs than any existing now.

When this happens, much of the short-range transport – at least in rural areas – may once again be non-mechanical, though not necessarily equine. The horse may not turn out to be the best choice in the long run; something like a ‘compact’ elephant might be preferable, because of its dexterity. (It is the only quadruped that can carry out delicate handling operations while remaining a quadruped.) In any event it should be herbivorous; carnivores are much too expensive to feed, and might take a fancy to their riders.

What I am suggesting is an animal large enough to carry a man at a fair speed, and intelligent enough to forage for itself without creating a nuisance or getting lost. It would report for duty at regular times, or when summoned over a radio command circuit, and it could carry out many simple errands by itself, without direct human supervision. It seems to me that there would be quite a demand for such a creature; and where there is a demand, eventually there is a supply.

Turning from this biological wishful-thinking back to the world of machinery, the only novel item in the Very Short Range category is the Conveyor. By this I mean all continuously moving systems such as escalators or the ‘Moving Ways’ described by H. G. Wells in *The Sleeper Wakes.*

A few small-scale experiments in pedestrian conveyor systems have already been made in New York and London, to remove the notorious bottlenecks between Grand Central Station and Times Square, and between the Monument and the Bank. A sane city, designed from the ground up for the convenience of its inhabitants, would be criss-crossed with slowly moving pavements at different levels; perhaps the north-south ones would be on the even levels, the east-west ones on the odd, with frequent change-over points between them.

The layout of a conveyor-belt city would be somewhat dull and mechanical, for obvious engineering reasons, though it need not be as monotonously rectilinear as Manhattan. I suspect that the greatest difficulties in the way of its realization would not be technical or economic, but social. The idea of free public transport, though it makes good commonsense, will be anathema to a great many people. Already I can picture the violent campaign the Taxi Driver’s Union would launch in favour of rugged individualism, against the horrors of socialized transportation.

Yet it is becoming obvious that vehicles – except public utility ones – cannot be permitted much longer in urban areas. We have taken some time to face this fact; more than two thousand years have passed since increasing traffic congestion in Rome compelled Julius Caesar to ban all wheeled vehicles during the hours of daylight, and the situation has become slightly worse since 46 BC. If private cars are to continue to operate inside the cities, we will have to put all the buildings on stilts so that the entire ground area can be used for highways and parking lots – and even this may not solve the problem.

Though it seems unlikely that pedestrian conveyors will ever be used except over short distances, there is some possibility that they may have wider applications. About thirty years ago, in a short story, *The Roads Must Roll,* Robert Heinlein suggested that travel even over considerable distances would one day be based on the conveyor-belt system – if only because the mounting carnage of the Petrol War rules out the continued use of automobiles. Heinlein developed, in his usual meticulous detail, both the sociology and the technology of the Rolling Road culture. He imagined vast multi-strip highways, with central express sections travelling at 100 mph, complete with dining-places and rest rooms.

The engineering problems of such a system would be enormous, but not insuperable (they could hardly be compared with those overcome in the development of nuclear weapons, though the capital sums involved would be even greater). It is my own feeling, however, that the mechanical difficulties would be so serious that their solution *in terms of present-day technology* would not be worth the trouble; Heinlein himself was careful to point out what might happen if a high-speed belt snapped with a few thousand passengers aboard it …

The fundamental problem of continuously moving pedestrian conveyors is: how do you get on to them safely? Anyone who has observed a nervous old lady hovering on the brink of an escalator will appreciate this point, and I do not think that we can expect ordinary members of the public, possibly loaded down with shopping or infants, to cope with speed differentials of over 5 mph. This means that a large number of adjacent bands will be required if we hope to build express-ways travelling at fifty or more miles an hour at their centre.

The ideal moving road would be one that had a *smoothly* increasing speed gradient from edge to centre, so that there were no sudden jumps in velocity. No solid material can behave in this manner, and at first sight the concept appears to be physically unrealizable. But is it?

The flow of a river exhibits this kind of behaviour. Immediately adjacent to the bank, the liquid is motionless; then the velocity of the surface layer increases steadily towards the middle, falling off again towards the other bank. You can prove this by dropping a line of corks across a uniformly flowing river; the line will quickly bow into a curve as the corks at the centre move ahead of those at the edge. Nature has provided the prototype of the perfect moving way – for those small insects that can walk on water.

In one of my earlier novels* I suggested, not very seriously, that we might some day invent or develop a material that would be sufficiently solid in the vertical direction to support the weight of a man, yet fluid enough in the horizontal plane to allow it to move at variable speeds. A great many substances are in some degree ‘anisotropic’ – that is, their properties vary in different directions. The classic example is wood; as every carpenter knows, its behaviour along the grain is completely different from that at right angles to it.

Perhaps local electric, magnetic or other fields, acting on powders or dense liquids, might produce the desired anisotropic effect; remember what happens to iron filings in the presence of a magnetic field. What I am trying to visualize (and I must admit that this is hopeful whistling in the technological dark) is a fairly thin layer of Substance X, supported on a fixed solid base within which the necessary polarizing fields are generated. These fields give X its rigidity in the vertical direction, and also impart the desired velocity gradient across the strip. You can step on to the edge with perfect confidence, because it is almost stationary. But if you walk towards the centre, you will experience a smooth and steady increase in speed until you reach the Express section. There would be no sudden jumps, as is inevitable with any system of parallel belts.

A continuous speed variation right across the road would be quite annoying; it would be impossible to stand still, for one foot would creep ahead of the other. The solution would be to have fairly wide uniform velocity bands, which might be marked out by coloured lighting, separated by narrow transition strips where the speed increased rapidly but smoothly. The bands could be easily varied in width and direction according to the flow of traffic, merely by altering the pattern of the field that produced them. At the end of the road, the field would be switched off, Substance X would revert to a normal, well-behaved liquid or powder, and could be pumped back to the beginning of the circuit through pipelines.

The whole concept is so beautiful, and such an improvement on the conventional scheme of moving belts, that it will be a great pity if it turns out to be totally impossible …

On the other hand, there may be still more advanced solutions to the problem of pedestrian traffic. If we ever discover a method of controlling gravity (a possibility to be discussed in more detail in Chapter 5), that will give us much greater powers than the neutralization of weight. We will be able to produce not only levitation but guided movement in any desired direction – up or down, horizontally or vertically.

Because our generation has already known the ‘weightlessness’ of sea and space, we should not find completely fantastic the picture of a city full of effortlessly floating pedestrians – if one can still call them that. It is a little hair-raising, though, to realize what vertical transportation would imply in a structure the size of the Empire State Building. There would be no elevator cages – just plain shafts, straight up and down for a thousand feet. But to their occupants, under the influence of a gravity field that had been artificially twisted through ninety degrees, they would appear to be *horizontal* tunnels along which they were being swept like thistledown before a gentle breeze. Only if the power failed would they come back to reality with, if you will pardon the metaphor, a bump.

It is obvious that anyone from our age would not last for long, physically or psychologically, inside such a city. But how long would a man from 1800 survive in one of ours?

Even if they are banned from the city, motor vehicles are likely to dominate the short (10-100 mile) range of transportation for a long time to come. There are few men now alive who can remember when it was otherwise; the automobile is so much a part of our existence that it seems hard to believe that it is a child of our century.

Looked at dispassionately, it is an incredible device, which no sane society would tolerate. If anyone before 1900 could have seen the approaches to a modern city on a Monday morning or a Friday evening, he might have imagined that he was in Hell – and he would not be far wrong.

Here we have a situation in which millions of vehicles, each a miracle of (often unnecessary) complication, are hurtling in all directions under the impulse of anything up to two hundred horsepower. Many of them are the size of small houses and contain a couple of tons of sophisticated alloys – yet often carry a single passenger. They can travel at 100 mph, but are lucky if they average twenty. In one lifetime they have consumed more irreplaceable fuel than has been used in the whole previous history of mankind. The roads to support them, inadequate though they are, cost as much as a small war; the analogy is a good one, for the casualties are on the same scale.

Yet despite the appalling expense in spiritual as well as material values (look what Detroit has done to aesthetics) our civilization could not survive for ten minutes without the automobile. Though it can obviously be improved, it seems hard to believe that it can be replaced by anything fundamentally different. The world has moved on wheels for 6,000 years, and there is an unbroken sequence from the ox-cart to the Cadillac.

Yet one day that sequence will be broken – perhaps by Ground Effect Vehicles riding on airblasts, perhaps by gravity control, perhaps by still more revolutionary means. I shall discuss these possibilities elsewhere; meanwhile, let us take a brief glance at the future of the automobile as we know it.

It will become much lighter – and hence more efficient – as materials improve.

Its complicated and toxic petrol engine (which has probably killed as many people by air-pollution as by direct physical impact) will be replaced by clean and silent electric motors, built into the wheels themselves and so wasting no body-space. This implies, of course, the development of a really compact and light-weight method of storing or producing electricity, at least an order of magnitude better than our present clumsy batteries. Such an invention has been overdue for about fifty years; it may be made possible either through improvements in fuel cells, or as a by-product of solid-state physics.

These improvements, however, will be much less important than the fact that the automobile of the day-after-tomorrow will not be driven by its owner, but by itself; indeed, it may one day be a serious offence to drive an automobile on a public highway. I would not care to say how long it will take to introduce completely computerized motoring, but dozens of techniques already developed by airlines and railroads already point the way to it. Automatic blocks, electronic road signs, radar obstacle detectors, navigational grids – even today we can visualize the basic elements required. An automatic highway system will, of course, be fabulously expensive to install and maintain – but in the long run it will be much cheaper, in terms of time, frustration and human lives, than the present manual one.

The automobile of the future will really live up to the first half of its name; you need merely tell it your destination – by dialling a code, or perhaps even verbally – and it will travel there by the most efficient route, after first checking with the highway information system for blockages and traffic jams. As a mere incidental, this would virtually solve the parking problem. Once your car had delivered you at the office, you could instruct it to head out of town again. It would then report for duty in the evening when summoned by radio, or at a prearranged time. This is only one of the advantages of having a built-in chauffeur.

Some people, I know, enjoy driving, for reasons which are simple and Freudian, though none the worse for that. Their desires could easily be fulfilled at suitable times and places – but *not* on the public highways. For my own part, I steadfastly refuse to have anything to do with vehicles in which I cannot read when I am travelling. It is therefore impossible for me to own a car; at this early stage in its technical development, a car would own me.

The most revolutionary – indeed, from the viewpoint of our grandfathers the most incredible – event in the history of transport has been the rise of aviation. Eventually all passenger traffic will go by air when stage-lengths of more than a couple of hundred miles are concerned; the railroads recognize this, as is proved by their often unconcealed efforts to discourage customers. They would much prefer to concentrate on freight, which is more profitable and far less troublesome, for it is seldom in a frantic hurry and does not object to being parked in sidings for a few hours. Nor does it insist that its feet be warmed and its martinis chilled – *vide* Peter Arno’s famous cartoon.

The story of the railroads, which have served mankind so well for almost a century and a half, is now entering its final chapter. As industry becomes decentralized, as the use of coal for fuel diminishes and nuclear power enables the factories to move nearer to their sources of supply, so the very need for shifting megatons of raw materials over thousands of miles will dwindle away. With it will pass the chief function of the railroad, which has always been the moving of freight, not of passengers.

Already some young countries – Australia, for example – have virtually by-passed the railroad age and are building transportation systems based on highways and airlines. In a few more decades, today’s Pullmans and diners and roomettes will be as much period pieces as the Mississippi paddle-boats, and will evoke equal nostalgia.

Nevertheless, by a strange paradox it is quite possible that the heroic age of railroads still lies ahead. On airless worlds like the Moon, Mercury and the satellites of the giant planets, alternative forms of transport may be impracticable, and the absence of atmosphere will permit very high speeds even at ground level. Such a situation almost demands railroads – using that term to mean any system employing fixed tracks. On rugged, low-gravity worlds there is a good deal to be said for monorails or cars suspended from overhead cables, which could be slung across valleys and chasms and craters, with complete indifference to the geography below them. A century from now, the face of the Moon may be covered with such a network, linking together the pressurized cities of the first extra-terrestrial colony.

Meanwhile, back on Earth, the flow of passenger traffic into the air will be still further accelerated when VTOL (Vertical Take-off and Landing) aircraft are perfected. Though the helicopter, for all its importance in more specialized fields, has had little effect on public transportation, this will not be true of its successors, the short- and medium-range air-buses of the near future. What form they will take, and what principle they will operate on, no one can foresee at the moment – but no one has any doubts that practical versions will soon be developed from some or other of the horrid-looking devices that are now laboriously heaving themselves off the ground with the aid of jets, rotors or tilting wings. We will not have conquered the air until we can go straight up and come straight down – as slowly as we please.

As far as intercontinental transportation is concerned, the battle is already over, the decision already made. Where speed is required, the airlines have no competition. Indeed, the ridiculous situation has now been reached where travelling to and from the airport, and getting through the Paper Curtains at either end, takes longer than a transatlantic flight.

Nevertheless, aircraft speeds will increase very substantially over the next few decades, and such restrictions as exist are economic rather than technological. (The airlines have to pay for the current generation of jets, and would be most unhappy if suddenly confronted with the supersonic transports they fully expect to be buying in the 1970s.) This belief that major advances in performance are still to come is an aftermath of the jet and rocket revolutions of the 1945-55 period, when all existing records were so thoroughly shattered that conservatism about the future seemed ludicrous.

That was not always the case, as the examples I have given in Chapter 1 demonstrated. I would like to give one more, because it is easy to forget how often the views of technical and scientific authorities about future progress fall hopelessly short' of the truth. Yet the 'experts' continue to make the same mistakes, and many of them will go through their predictable routines again when these words appear in print.

Back in 1929, a leading aeronautical engineer, now well known to you in quite a different connexion (I'll give his name in a moment) wrote a paper on the future of aviation which opened with the words: 'The forecast is freely made that within a few years passenger-carrying aeroplanes will be travelling at over 300 mph, the speed record today.' This, he stated pontificially, was gross journalistic exaggeration, as 'the commercial aeroplane will have a definite range of development ahead of it beyond which no further advance can be anticipated.'

Here are the advances this far-sighted prophet anticipated when the aeroplane had reached the limit of its development, *probably by the year 1980:*

Speed: 110-130 mph
Range: 600 miles
Payload: 4 tons
Total weight: 20 tons

Well, every one of these figures had been multiplied by more than five by the time their proponent died in 1960, mourned by thousands of readers in many countries. For in 1929 he was N. S. Norway, chief calculator on the R100 airship design; but in 1960 he was famous as Nevil Shute. One can only hope, as he himself must have done, that *On the Beach* turns out to be as wide of the mark as this earlier and lesser-known prediction.

Even the earliest versions of the *Concorde* demonstrated that we can build 'conventional' jet transports operating at speeds of one or two thousand miles an hour. This would mean that no journey on Earth could last for more than six hours, and very few would be of over two or three hours' duration. A world-wide pattern of long-distance mass-transportation might develop, far more like today's bus and rail services than anything now offered by the airlines. Meals and stewardesses would be as inappropriate as on the IRT or the London Underground; the analogy may be all too close, for some operators have suggested that ultra-cheap air-coaches could be run on a Standing Room Only basis. Those who have already experienced the joys of a Transatlantic Economy Flight in the company of a dozen bilious babies may be glad to know that the future has yet deeper delights in store.

In the face of competition from the air, the shipping lines have wisely concentrated on selling comfort and leisure. Although on most routes more passengers now travel by air than by sea, this traffic has not all been won at the expense of the ocean liners. Indeed, there has been (at least in Europe) a major building programme which has seen the launching of such magnificent ships as *Oriana*, *Leonardo da Vinci* and *Canberra.* Some of these are pure passenger vessels – that is, they do not rely on freight for any part of their income. Whatever the future brings, such ships will continue to ply the ocean for as long as men remain men and feel the call of their ancient home, the sea.

The end of the freight-carrying ship – the tramps and the windjammers and the galleons and the quinquiremes which for six thousand years have carried the cargoes of the world – is already in sight; in another century, only a few will be left as picturesque survivals in out-of-the-way places. After ages without a rival, the cargo-ship is now challenged simultaneously on three fronts.

One challenge is from *below* the water. The submarine is a much more efficient vehicle than the surface ship, which wastes much of its energy on the production of waves. With the advent of nuclear energy, the high-speed, long-range submarine envisaged years ago by Jules Verne is at last practical, but so far has been developed only for military purposes. Whether the heavy initial cost, and the problems of underwater operation, will make the cargo-submarine economical is another question.

An interesting compromise which almost certainly is economical is the flexible towed container now being developed in the United Kingdom for liquid cargoes. These giant plastic sausages (which can be rolled up and shipped – or even flown – cheaply from point to point when they are not in use) have now been built in lengths of up to two hundred feet, and there is no obvious limit to size. Since they can be towed completely submerged, they have the efficiency of the submarine without its mechanical and navigational complications. And they can be built very lightly and cheaply, since their structural strength is extremely low. Unlike rigid ships, they do not resist waves, but give with them. They will even ‘kink’ at sharp angles when their tug makes an abrupt turn.

With commendable honesty, the inventor of the ‘Dracone’ (the trade-name for the flexible submarine tanker) has admitted ‘I got the idea from a science-fiction story’. This was presumably Frank Herbert’s excellent novel *The Dragon in the Sea*,* which dealt with a hair-raising wartime voyage by an atomic submarine towing a string of submersible oil-barges. It is, indeed, as oil-tankers that such vessels may have their greatest use: petroleum products constitute half of the world’s total of goods moved by sea, now running at about a billion tons a year. Certain Greek ship-owners may well view with apprehension the replacement of their beautiful tankers by overgrown plastic bottles.

Other bulk cargoes (grain, coal, minerals and raw materials generally) could be carried in the same manner. In most of these cases, speed is not important; what matters is that a continuous flow be maintained. Where speed is vital, airfreight will be used for all except the bulkiest cargoes; and one day, even for these.

Air transport is just at the beginning of its evolution; to set limits to what it may become would be folly, as the examples I have quoted clearly show. Though less than 0.1 per cent of today’s freight travels by air, the time may come when it will all do so. Some of it may fly thousands of feet in the sky; but some – and perhaps most of it – may rise only a few inches above the ground. For the nemesis of the ocean-going freighter may not be the submarine or the aeroplane, but the Ground Effect Machine, riding on curtains of air over land and sea.

This novel and quite unexpected development may be important and not only in itself but as a pointer to the future. For the first time it allows us to float really heavy loads in the air. This may or may not revolutionize transport, but it will certainly set men thinking seriously about genuine gravity control, one rather trivial application of which I have already mentioned.

Gravity control – ‘anti-gravity’, as the science-fiction writers call it – may prove to be impossible, but the Ground Effect Machine is already here. Now let us see what it, and its hypothetical successor, may do to our civilization.

FOUR

RIDING ON AIR

Our century has seen two great revolutions in transport, each of which has changed the very pattern of human society. The automobile and the aeroplane have created a world that no man of a hundred years ago could have conceived in his wildest dreams. Yet both are now being challenged by something so new that it does not even have a name – something that may make the future as strange and alien to us as our world of super-highways and giant airports would be to a man from 1890. For this third revolution may bring about the passing of the wheel, our faithful servant since the dawn of history.

In many countries – the United States, England, the USSR, Switzerland, and doubtless elsewhere – major engineering efforts are now in progress to develop vehicles which literally float on air. The pioneering Saunders – Roe SR–N1 'Hovercraft' led to the 160-ton SR–N4s which have ferried thousands of passengers across the English Channel, and far larger models are on the drawing board. They all depend for their operation on what is known as 'Ground Effect', and for this reason have been called Ground Effect Machines or GEMs.

Though GEMs, since they support themselves by downward blasts of air, have a superficial resemblance to helicopters, they operate on quite different principles. If you are content to float only a few inches from the ground, you can support, *for the same horsepower*, many times the load that a helicopter can lift into the open sky. You can demonstrate this in your own home by an extremely simple experiment.

Suspend an electric fan in the middle of the room, so that it is free to move back and forth; then switch it on. You will find that the fan recoils a quarter of an inch or so, owing to the blast of air it produces. The thrust is not very great, yet this is the effect which drives all our aeroplanes and helicopters through the sky.

Now take the same fan and hang it facing the wall, as close to it as the wire guard will allow you. This time, when you switch on, you will find that the recoil is two or three times greater than before, because some of the air-blast is being trapped as a kind of cushion between the fan and the wall. The more effective the trapping, the bigger the recoil. If you fitted a shroud of cowling round the fan, to prevent the air from spilling out in all directions, the kick would increase still further.

This tells us what we must do if we wish to ride on a cushion of air. We need a flat surface, and a slightly hollowed plate lying on top of it – a saucer, face downwards, will do very nicely. If we blow into the saucer with sufficient force, it will rise until the air spills out round the rim, and will remain floating a fraction of an inch above the ground.

In the right circumstances, even a small quantity of air can produce a remarkable amount of lift. The scientists of the European Centre for Nuclear Research (CERN) recently put this effect to good use. They were confronted with the problem of moving equipment weighing up to three hundred tons – and, even trickier, of positioning it in the laboratory to within a fraction of a millimetre.

So they used saucer-shaped steel discs, about a yard across, with rubber gaskets round the edges. When air at a pressure of seventy pounds per square inch is blown into such a pad, it can lift ten or twenty tons with ease. Equally important, there is so little friction than you can push the load around the lab with your fingers.

It is obvious that industry and heavy engineering will find many uses for these Floating Saucers, and one trivial but amusing application of them has already entered the home. There is now a vacuum cleaner on the market that drifts effortlessly above the carpet, supported on its own exhaust, so that the busy housewife can get back to the TV set that vital few seconds earlier.

But what has all this got to do, you may wonder, with general transportation? There are not many road surfaces as smooth as laboratory floors, or even dining-room carpets, so it would hardly seem that the good old-fashioned wheel has much to worry about.

However, this is a short-sighted view, as the scientists who started looking into the theory of the ground effect soon discovered. Although the small-scale devices just mentioned will operate only on smooth, flat surfaces, when they are built in larger sizes the situation is completely different – and fraught with excitement to the transportation engineer.

For the bigger you make your GEM, the higher it will ride off the ground and, therefore, the rougher the terrain it can cross. The Saunders-Roe SR–N1 skimmed along at a maximum altitude of fifteen inches, but its larger successors will float at shoulder height on the invisible cushion formed by their curtains of downward-moving air.

Because they have no physical contact with the surface beneath them, GEMs can travel with equal ease over ice, snow, sand, ploughed fields, swamps, molten lava – you name it, the GEM can cross it. All other transport vehicles are specialized beasts, able to tackle only one or two kinds of terrain; and nothing has yet been invented that can travel swiftly and smoothly over a single one of the surfaces just mentioned. But to the GEM they are all alike – *and a superhighway is no better*.

It takes some time to grasp this idea, and to realize that the immense networks of roads upon which two generations of mankind have spent a substantial fraction of their wealth may soon become obsolete. Traffic lanes of a sort would still be needed, of course, to keep vehicles out of residential areas, and to avoid the chaos that would result if every driver took the straightest line to his destination that geography allowed. But they need no longer be paved – they would merely be graded, so that they were clear of obstacles more than, say, six inches high. They would not even have to be laid on good foundations, for the weight of a GEM is spread over several square yards, not concentrated at a few points of contact.

Today's turnpikes might well last for generations without any further maintenance, if they had to carry only air-supported vehicles; the concrete could crack and become covered with moss – it would not matter in the least. There will clearly be enormous savings in road costs – amounting to billions a year – once we have abolished the wheel. But there will be a very difficult transition period before the characteristic road-sign of the 1990s becomes universal: NO WHEELED VEHICLES ALLOWED ON THIS HIGHWAY …

Since the GEMs or Aircars of the future need stick to the traffic lanes only when their drivers feel like it, the chief motoring offence at the turn of the century will not be speeding, but trespass. It is too much to expect that refugees from the cities, with the power to move like clouds over the length and breadth of the land, will refrain from entering and exploring any attractive piece of scenery that takes their fancy. Barbed-wire may make a second debut in the West as irate farmers try to keep weekenders from littering their land with picnic trash. Strategically placed rocks would be more effective, but they would have to be spaced close together, otherwise the invaders could slip between them.

There are few spots that a skilful aircar driver could not reach, and the breakdown vans of the future are going to receive SOS calls from families stranded in some very odd places. The Grand Canyon, for example – what a challenge that presents to the air-borne motorist! It might even be possible to develop a specialized form of GEM that could climb mountains; the driver could take his time – and throw out ground anchors if necessary – as he worked his way cautiously up slanting surfaces of rock, snow or ice. But this would, definitely, not be an operation for beginners.

If such ideas seem a little far-fetched, that is because we still belong to the age of the wheel, and our minds cannot free themselves from its tyranny – perfectly summed up in the warning SOFT SHOULDERS. This is a phrase that will be meaningless to our grandchildren; to them, if a surface is reasonably plane, it will not matter whether it consists of concrete or quagmire.

It is only fair to point out that the large-scale use of private or family GEMs may not be a very practical proposition while we have to depend on the petrol engine. Apart from the noise – and dust – it requires several hundred hp to produce speeds of only 60 mph. Although there will certainly be great improvements in performance, it seems that at the present moment the smaller types of GEM are of interest chiefly to the armed forces, farmers who have to deal with broken or flooded land, movie directors after unusual tracking shots, and similar specialized customers who can foot the petrol bills.

But the petrol engine is on its way out, as any petroleum geologist will assure you in his more unguarded moments. Before very much longer, out of sheer necessity, we must find some other source of power – perhaps a sophisticated type of electric battery, with at least a hundred times the capacity of today's clumsy monsters. Whatever the answer, within a few more decades there will be light-weight, long-endurance motors of some kind, ready to take over when the oil wells run dry. These will power the private aircars of the future, as the petrol engine has driven the earthbound automobiles of the past.

With the emancipation of traffic from the road, we will at last have achieved real mobility over the face of the earth. The importance of this to Africa, Australia, South America, Antarctica and all countries that lack (and now may never possess) well-developed highway systems can scarcely be over-estimated. Pampas, steppes, veldt, prairies, snowfields, swamps, deserts – all will be able to carry heavy, high-speed traffic more smoothly, and perhaps more economically, than the finest roads that exist today. The opening up of the polar regions may well depend upon the speed with which freight-carrying GEMs are developed.

We will return to this subject later, but now it is time to go to sea. For GEMs, of course, can travel with equal ease over land or water. As they grow larger and faster, these vehicles may have a revolutionary effect upon commerce, international politics, and even the distribution of population. We do not need any hypothetical new power plants to make them practical; when we start thinking in terms of thousands of tons, today's gas-turbines are quite adequate and tomorrow's nuclear reactors will be even better. As soon as we have gathered enough experience from the present primitive models, we will be able to build giant, ocean-going GEMs capable of carrying intercontinental cargoes at speeds of at least 100 mph.

Unlike today's ships, the air-supported liners and freighters of the next generation will be low, flat-bottomed vessels. They will be extremely manoeuvrable – GEMs can move backwards or sideways simply by altering the direction of their airblasts – and will normally float at an altitude of about ten feet. This will enable them to skim smoothly over all but the very roughest seas. One consequence of this is that they could be quite lightly constructed, and would, therefore, be much more efficient than sea-borne ships, which must be built to withstand enormous stresses and strains.

Their speed would enable them to outrun or avoid all storms; in any event, by the time they become operational the meteorological satellites will have provided us with a worldwide weather service, and every captain will know exactly what to expect during the few hours he is at sea. In a hurricane, a large GEM might even be safer than a conventional ship of the same size, for it would be above most of the wave action.

Because a 'hovership' is completely indifferent to breakers, reefs and shoals, it could operate in waters where no other type of marine craft could navigate. This may open up to commercial and game fishermen, thousands of square miles of absolutely virgin territory, and may revolutionize the life of island communities. Vast areas of the Great Barrier Reef – the 1,200-mile long coral rampart guarding the north-eastern coast of Australia – are almost inaccessible except in a dead calm, and many of its smaller islands have never been visited by man. A reliable GEM bus service would, alas, turn these minute pandanus-clad jewels into desirable housing estates and holiday resorts.

As the GEM is the most frictionless type of vehicle yet invented, it can certainly travel much faster than any existing type of marine craft, including 300 mph jet-propelled hydroplanes. This suggests that the airlines may be in for some stiff competition, for there are many passengers willing to spend days – but not weeks – at sea, especially if a smooth ride can be guaranteed. A vessel that could cruise at a modest 150 mph could get from London to New York in a day, thus neatly plugging the gap in the speed spectrum between the QEII and the Boeing 707.

What makes the GEM so attractive as a passenger vehicle is its built-in safety factor. When the engines of an airliner fail, or any major defect develops in the structure, there is little hope for those aboard. But almost anything could happen to a GEM, short of a head-on collision, and it would gently settle down on to its floats, without spilling a single drink in the bar. It would have no need for the immensely elaborate and expensive navigational and safety networks essential for air transport; in an emergency, the captain could always sit tight and think matters over, without worrying about his fuel reserve. From this point of view, GEMs seem to combine the best factors of ships and aircraft, with remarkably few of their disadvantages.

The most shattering implications of GEMs do not, however, arise from their speed or their safety, but from the fact that they can ignore the divisions between land and sea. An ocean-going GEM need not stop at the coastline: it can continue on inland with a supreme indifference to the great harbours and seaports that have been established by five thousand years of maritime commerce.

Any stretch of coast that was not fronted by sheer cliffs would be an open door to GEM freighter or liners. They could continue on inland with scarcely a pause for a thousand miles if needs be, to deliver cargoes and passengers in the heart of a continent. All they would require would be fairly wide traffic lanes or throughways, clear of obstacles more than a yard or two in height; old railway tracks, of which there will be a good supply by the close of this century, will do excellently. And these lanes need not be dead ground, as are today's highways and railroads. They could be used for a wide variety of agricultural purposes – though not, it must be admitted, for the growing of wheat. The man-made gales would be a little too severe.

All this is very bad news for San Francisco, New Orleans, London, Los Angeles, Naples, Marseilles and any other seaport you care to name. But it is much worse news for Egypt and Panama.

Precisely. The 'ships' of the future are not going to crawl along narrow ditches at five miles and at a 1,000 dollars an hour, when they can skim over land at twenty times the speed – *and can pick and choose their routes with almost the same freedom as in the open sea.*

The political consequences of this will be, to say the least, extremely interesting. The entire Middle East situation would be very different if Israel (or for that matter half a dozen other countries) could put the Suez Canal *permanently* out of business merely by offering unspoilt desert on highly competitive terms. And as for Panama – I will leave that for the quiet contemplation of the US Navy and State Department.

It is an instructive and mind-stretching exercise to take a relief map of the world, and to imagine where the GEM trade-routes of the future will lie. Half a century from now, will Oklahoma City be a greater port than Chicago? (Think of the millions of tons of shipping that could manoeuvre on the Great Plains!) What is the best way to take a hundred-thousand-ton freighter through the Rockies, the Andes or the Himalayas? Will Switzerland become a major ship-building nation? Will purely water-borne craft survive at all, when land and ocean becomes a single continuum?

These are questions that we will soon have to answer. The sudden and unexpected development of the GEM requires us to indulge in some particularly agile mental gymnastics; in our preoccupation, with cargoes hurled through the upper atmosphere at the speed of sound, we have completely overlooked a major revolution at sea level.

One which may, quite literally, have brought us to the end of the road.

FIVE

BEYOND GRAVITY

Of all the natural forces, gravity is the most mysterious and the most implacable. It controls our lives from birth to death, killing or maiming us if we make the slightest slip. No wonder that, conscious of their earth-bound slavery, men have always looked wistfully at birds and clouds, and have pictured the sky as the abode of the gods. The very phrase ‘heavenly being’ implies a freedom from gravity which, until the present, we have known only in our dreams.

There have been many explanations of those dreams, some psychologists trying to find their origin in our assumed arboreal past – though it is unlikely that many of our direct ancestors ever spent their lives jumping from tree to tree. One could argue just as convincingly that the familiar levitation dream is not a memory from the past, but a premonition from the future. Some day ‘weightlessness’ or reduced gravity will be a common, and perhaps even a normal, state of mankind. The day may come when there are more people living on space-stations and worlds of low gravity than on this planet; indeed, when the history of the human race is written, the estimated 100 billion men who have already spent laborious lives struggling against gravitation may turn out to be a tiny minority. Perhaps our space-faring descendants will be as little concerned with gravity as were our remote ancestors, when they floated effortlessly in the buoyant sea.

Even now, most of the creatures on this planet are hardly aware that gravity exists. Though it dominates the lives of large land animals such as elephants, horses, men and dogs, to anything much smaller than a mouse it is seldom more than a mild inconvenience. To the insects it is not even that; flies and mosquitoes are so light and fragile that the air itself buoys them up, and gravity bothers them no more than it does a fish.

But it bothers us a great deal, especially now that we are making determined efforts to escape from it. Quite apart from our current interest in space-flight, the problem of gravitation has always worried physicists. It seems to stand completely apart from all the other forces – light, heat, electricity, magnetism – which can be generated in many different ways, and are freely interconvertible.

Indeed, most of modern technology is based upon such conversions – of heat into electricity, electricity into light, and so on.

Yet we cannot generate gravity at all, and it appears completely indifferent to all the influences which we may bring to bear on it. As far as we know, the only way a gravitational field can be produced is by the presence of matter. Every particle of matter has an attraction for every other particle of matter in the universe, and the sum total of those attractions, in any one spot, is the local gravity. Naturally, this varies from world to world, since some planets contain large amounts of matter and others very little. In our solar system the four giant planets Jupiter, Saturn, Uranus and Neptune all have surface gravities greater than Earth's – two and a half times greater in the case of Jupiter. At the other extreme, there are moons and asteroids where gravity is so low that one would have to look hard at a falling object for the first few seconds to see that it was moving.

Gravitation is an incredibly, almost unimaginably, *weak* force. This may seem to contradict both common sense and everyday experience, yet when we consider the statement it is obviously true. Really gigantic quantities of matter – the six thousand million million million tons of the Earth – are required to produce the rather modest gravity field in which we live. We can generate magnetic or electric forces hundreds of times more powerful with a few pounds of iron or copper. When you lift a piece of iron with a simple horse-shoe magnet, the amount of metal the magnet contains is out-pulling the whole Earth. The extreme weakness of gravitational forces makes our total inability to control or modify them all the more puzzling and exasperating.

From time to time, one hears rumours that research teams are working on the problem of gravity control, or 'anti-gravity', but these stories always turn out to be misinterpretations. No competent scientist, at this stage of our ignorance, would deliberately set out to look for a way of overcoming gravity. What a number of physicists and mathematicians are doing, however, is something less ambitious; they are simply trying to uncover basic knowledge about gravity. If this plodding, fundamental work does lead to some form of gravity-control, that will be wonderful; but I doubt if many people in the field believe that it will. The opinion of most scientists is probably well summed up by a remark made by Dr John Pierce, late of the Bell Telephone Laboratories. 'Anti-gravity,' he said, 'is strictly for the birds.' But the birds don't need it – and we do.

There is some evidence, surprisingly enough, that businessmen and company executives are less sceptical than scientists about anti-gravity devices. In 1960 the *Harvard Business Review* carried out a 'Survey on the Space Programme', and received almost 2,000 replies to its detailed five-page questionnaire.

When asked to rate the degree of probability of various by-products of space research, the executives voted for anti-gravity as follows: Almost certain, 11 per cent; Very likely, 21 per cent; Possible, 42 per cent; Very unlikely, 21 per cent; Never will happen, 6 per cent. They rated it, in fact, as rather more likely than mining or colonizing the planets; I feel fairly confident that most scientists would consider it much *less* likely. However, at the present moment in time, the judgement of Harvard businessmen on the subject is likely to be just as good, or as bad, as that of professional physicists.

We still know so little about gravitation that we are not even absolutely sure if it travels through space at a definite speed – like radio or light waves – or whether it is 'always there'. Until the time of Einstein, scientists thought that the latter was the case, and that gravitation was propagated instantaneously. Today, the general opinion is that it travels at the speed of light and that, also like light, it has some kind of wave structure.

If 'gravitational waves' do exist, they will be fantastically difficult to detect, because they carry very little energy. It has been calculated that the gravity waves radiated by the whole Earth have an energy of about a millionth of a horsepower, and the total emission from the entire Solar System – the Sun and all the planets – is only half a horsepower. Any conceivable man-made gravitational-wave generator would be billions of billions of times feebler than this.

Nevertheless, attempts have been made to detect these waves. Success was first reported by Dr John Weber of the University of Maryland in 1969; he believes he has observed bursts of gravitational radiation coming from some unknown and mysterious source at the centre of the Galaxy. Exciting though these discoveries are, it will be a very long time before we can expect any practical applications from them. And it may be never.

Yet every few years, some hopeful inventor builds and actually demonstrates, at least to his own satisfaction, an anti-gravity device. These are always laboratory models, producing (or, rather, *apparently* producing) only a very tiny lift. Some of the machines are electrical, others purely mechanical, based on what might be called the 'bootstrap principle', and containing unbalanced flywheels, cranks, springs and oscillating weights. The idea behind these is that action and reaction may not always be equal and opposite, and there may sometimes be a little net force left over in one direction. Thus though everyone agrees that you can't lift yourself by a *steady* pull on your bootstraps, perhaps a series of properly timed jerks might have a different result …

Put this way, the idea seems completely absurd, but it is not easy to refute an intelligent and sincere inventor with a beautifully made machine containing dozens of parts, moving in every possible direction, who maintains that his oscillating contraption produces a net lift of half an ounce and that a bigger model could take you to the Moon. You may be 99.999 per cent sure that he is wrong, yet be quite unable to prove it. If gravity-control is ever discovered, it will surely depend upon much more sophisticated techniques than mechanical devices – and it will probably be found as a by-product of work in some completely unexpected field of physics.

It is also probable that we will not make much progress in understanding gravity until we are able to isolate ourselves and our instruments from it, by establishing laboratories in space. Attempting to study it on the Earth's surface is rather like testing hi-fi equipment in a boiler-factory; the effects we are looking for may be swamped by the background. Only in a satellite laboratory will we be able to investigate the properties of matter under weightless conditions.

The reason why objects are – usually – weightless in space is one of those elusive simplicities that is almost invariably misunderstood. Many people, misled by careless journalists, are still under the impression that an astronaut is weightless because he is 'beyond the pull of gravity'.

This is completely wrong. Nowhere in the universe – not even in the remotest galaxy that appears as a faint smudge on a Palomar photograph – would one be literally beyond the pull of Earth's gravity, though a few million miles away it is almost negligible. It falls off slowly with distance, and at the modest altitudes of the closer satellites and space-labs is still almost as powerful as at sea-level. When the first astronauts looked down on Earth from a height of 200 miles, the gravity field in which they were moving still held 90 per cent of its normal value. Yet, despite this, they weighed exactly nothing.

If this seems confusing, it is largely due to poor semantics. The trouble is that we dwellers on the Earth's surface have grown accustomed to using the words 'gravity' and 'weight' almost interchangeably. In ordinary terrestrial situations, this is safe enough; whenever there's weight there's gravity, and *vice versa*. But they are really quite separate entities, and either can occur independently of the other. In space, they normally do.

On occasion, they can do so on Earth, as the following experiment will prove. I suggest you think about it rather than actually conduct it, but if you are unconvinced by my logic, go right ahead. You will have the tremendous precedent of Galileo who also refused to accept argument but appealed to experimental proof. However, I disclaim all responsibility for any damage.

You will need a quick-acting trapdoor (one of those used by hangmen will do admirably) and a pair of bathroom scales. Put the scales on the trap door and stand on them. They will, of course, register your weight.

Now, while your eyes are fixed on the scale, get one of your acquaintances ('That's not an office for a friend, my lord,' as Volumnius said to Brutus on a slightly similar occasion) to spring the trapdoor. At once the needle will drop to zero; you will be weightless. But you will certainly not be beyond the pull of gravity; you will be 100 per cent under its influence, as you will discover a fraction of a second later.

Why are you weightless in these circumstances? Well, weight is a *force*, and a force cannot be felt if it has no point of application – if there is nothing for it to push against. You cannot feel any force when you push against a freely swinging door; nor can you feel any weight when you have no support and are falling freely. An astronaut, except when he is firing his rockets, is always falling freely. The 'fall' may be downwards or upwards or sideways – as in the case of an orbiting satellite, which is in an eternal fall around the world. The direction does not matter; as long as the fall is free and unrestrained, anyone experiencing it will be weightless.

You can be weightless, therefore, even when there is plenty of gravity. The reverse is also true; you don't need gravity to give you weight. A change of speed – in other words, an acceleration – will do just as well.

To prove this, let us imagine a still more improbable experiment than the one just described. Take your bathroom scales to a remote spot between the stars, where gravity is, for all practical purposes, zero. Floating there in space you will again be weightless; as you stand on the scales, they will read zero.

Now attach a rocket motor to the underside of the scales, and start it firing. As the scales press against your feet, you will feel a perfectly convincing sensation of weight. If the thrust of the rocket motor is correctly adjusted, it can give you, by virtue of your acceleration, exactly the same weight that you have on Earth. For all that you could tell, unless your other senses revealed the truth, you might be standing still on the surface of the Earth, feeling its gravity, instead of speeding between the stars.

This sensation of 'weight' produced by acceleration is quite familiar; we notice it in an elevator starting to move upwards, and – in the horizontal, not the vertical direction – in a car making a fast getaway or suddenly braking. It is possible to produce artificial weight of almost unlimited extent by the simple means of acceleration, and quite surprising amounts of it are encountered in everyday life. A child on a garden swing, for example, can easily range from zero weight at the upper limit of oscillation, when the swing is for an instant at rest, to three times normal weight at the bottom of the arc. And when you jump off a chair or a wall, the shock of hitting the ground can, momentarily, give you dozens of times your normal weight.

We measure such forces in terms of so many ‘gravities’ or ‘gees’, meaning that a person experiencing, say, l0g would feel ten times his ordinary weight. But the actual gravity of the Earth is not involved when the weight-force is produced wholly by acceleration, and it is unfortunate that the same word is used to describe an effect which may have two completely different causes.

The most convenient way of producing artificial weight is not acceleration in a straight line – which would quickly take one over the horizon – but motion in a circle. As anybody who has ridden a carousel knows, swift circular movement can generate substantial forces; this was the principle of the cream separators that some of us country boys can still remember from our days on the farm. The modern versions of these machines are the giant centrifuges now used in space-medicine research, which can easily give a man ten or twenty times his normal weight.

Small laboratory models can do far better than this. The Beams Ultracentrifuge, spinning at the unbelievable speed of 1,500,000 revolutions a *second* (not minute!), produces forces of more than a billion gravities. Here at any rate we have far outdone Nature; it seems most unlikely that there exist gravitational fields, anywhere in the Universe, more than a few hundred thousand times more powerful than Earth’s. (How wrong I was! See Chapter 9.)

It is easy enough, therefore, to produce artificial weight, and we may do just this in our spaceships and space-stations when we get tired of floating around inside them. A gentle spin will give a sensation which is indistinguishable from gravity – except for the minor point that ‘Up’ is towards the centre of the vehicle, not away from it as in the case of the Earth.

We can *imitate* gravity, then – but we cannot control it. Above all, we cannot cancel or neutralize it. True levitation is still a dream. The only ways in which we can hover in midair are by floating, with the aid of balloons, or by reaction, as with aeroplanes, helicopters, rockets and jet-lift devices. The first method is limited in scope and demands very large volumes of expensive or inflammable gases; the second is not only expensive but exceedingly noisy, and liable to let one down with a bump. What we would like is some nice, clean way, probably electrical or atomic, of abolishing gravity at the throw of a switch.

Despite the above-mentioned scepticism of the physicists, there seems no fundamental impossibility about such a device – as long as it obeys certain well-established natural laws. The most important of these is the principle of the conservation of energy, which may be paraphrased as: ‘You can’t get something for nothing.’

The conservation of energy at once rules out the delightfully simple ‘gravity screen’ used by H. G. Wells in *The First Men in the Moon.* In this greatest of all space-fantasies (which still retains its magic after three-quarters of a century) the scientist Cavor manufactured a material which was opaque to gravity, just as a sheet of metal is to light, or an insulator to electricity. A sphere coated with ‘Cavorite’ was able, according to Wells, to float away from the Earth with all its contents. By opening and closing the shutters, the space-travellers could move in any desired direction.

The idea sounds plausible – especially when Wells has finished with it – but unfortunately it just won’t work. Cavorite involves a physical contradiction, like the phrase, ‘An immoveable force and an irresistible object’. If Cavorite *did* exist, it could be used as a limitless source of energy. You could employ it to lift a heavy weight – then let the weight fall again under gravity to do work. The cycle could be repeated endlessly, giving that dream of all motorists – a fuelless engine. This, to everyone except inventors of perpetual motion machines, is an obvious impossibility.

Though gravity screens of this simple type can be dismissed, there is nothing inherently absurd in the idea that there may be substances which possess *negative* gravity, so that they fall upwards instead of downwards. From the nature of things, we would hardly expect to find such materials on Earth; they would float around out in space, avoiding the planets like the plague.

Negative gravity matter should not be confused with the – equally hypothetical – ‘anti-matter’ whose existence is postulated by some physicists. This is matter made up of fundamental particles with electric charges opposed to those in normal matter; thus electrons are replaced by positrons, and so on. Such a substance would still fall downwards, not upwards, in an ordinary gravitational field; but as soon as it came into contact with normal matter, the two masses would annihilate each other in a burst of energy far fiercer than that from an atomic bomb.

Anti-gravity matter would not be quite so tricky as this to handle, but it would certainly pose problems. To bring it *down* to Earth would require just as much energy as lifting the same amount of normal matter from Earth out into space. Thus an asteroid-miner who filled the hold of his space-jeep with negative-gravity matter would have a terrible time getting home. Earth would repel him with all its force, and he would have to fight every foot of the way downwards.

Thus negative-gravity substances, even if they exist, would have rather a restricted use. They might be employed as structural materials; buildings containing equal amounts of normal and negative-gravity matter would weigh exactly nothing, so could be of unlimited height. The architect’s main problem would be anchoring them against high winds.

It is conceivable that by some treatment we might permanently ‘degravitize’ ordinary substances, in much the same way that we can turn a piece of iron into a permanent magnet. (Less well known is the fact that continuously charged bodies – 'permanent electrets' – can also be made.) To do so would require a great expenditure of energy, for to degravitize one ton of matter is equivalent to lifting it completely away from the Earth. As any rocket engineer will tell you, this requires as much energy as raising 4,000 tons a height of one mile. That 4,000 mile-tons of energy is the price of weightlessness – the entrance fee to the universe. There are no concessions and no cheap rates. You may have to pay more, but you can never pay less.

On the whole, a permanently degravitized or weightless substance seems less plausible than the gravity neutralizer or 'gravitator'. This would be a device, supplied with energy from some external power-source, which would cancel gravity as long as it was switched on. It is important to realize that such a machine would give not only weightlessness, but something even more valuable – propulsion.

For if we exactly neutralized weight, we would float motionless in mid-air; but if we over-neutralized it, we would shoot upwards with steadily increasing speed. Thus any form of gravity control would also be a propulsion system; we should expect this, as gravity and acceleration are so intimately linked. It would be a wholly novel form of propulsion, and it is difficult to see what it would 'push against'. Every prime mover must have some point of reaction; even the rocket, the only known device that can give us a thrust in a vacuum, pushes on its own burnt exhaust gases.

The term 'Space Drive', or just plain 'Drive', has been coined for such non-existent but highly desirable propulsion systems, not to be confused with the Overdrives and Under-drives peddled by Detroit. It is an act of faith among science-fiction writers, and an increasing number of people in the astronautics business, that there must be some safer, quieter, cheaper and generally less messy way of getting to the planets than the rocket. The monsters standing at Cape Kennedy contain as much energy as the first atomic bomb in their fuel tanks – and it is less reliably controlled. Sooner or later there is going to be a really nasty accident [*]; we need a space drive urgently, not only to explore the solar system, but to protect the state of Florida.

It may seem a little premature to speculate about the uses of a device which may not even be possible, and is certainly beyond the present horizon of science. But it is a general rule that, whenever there is a technical need, something always comes along to satisfy it – or to by-pass it. For this reason, I feel sure that eventually we will have some means of either neutralising gravity or overpowering it by brute force. In any event, it will give us both levitation and propulsion, in amounts determined only by the available power.

If anti-gravity devices turn out to be bulky and expensive, their use will be limited to fixed installations and to large vehicles – perhaps of a size which we have not yet seen on this planet. Much of the energy of mankind is expended in moving vast quantities of oil, coal, ores and other raw materials from point to point – quantities measured in hundreds of millions of tons per year. Many of the world's mineral deposits are useless, because they are inaccessible; perhaps we may be able to open them up through the air, by the use of relatively slow-moving anti-gravity freighters hauling a few hundred thousand tons at a time across the sky.

One can even imagine the bulk movement of freight or raw materials along 'gravity pipelines' – directed and focused fields in which objects would be supported and would move like iron towards a magnet. Our descendants may be quite accustomed to seeing their goods and chattels sailing from place to place without visible means of support. On an even larger scale, gravity and propulsion fields might be used to control and redirect the winds and the ocean currents; if weather modification is ever to be practical, something of this sort is certainly necessary.

The value of gravity control for space-vehicles, both for propulsion and the comfort of their occupants, needs no further discussion – but there are other astronautical uses that are not so obvious. Jupiter, the largest of the planets, is barred from direct human exploration by its high gravity, two and a half times that of Earth. This giant world has so many other unpleasant characteristics (an enormously dense, turbulent and poisonous atmosphere, for example) that few people take very seriously the idea that we will ever attempt its manned exploration; the assumption is that we will always rely on robots.

I doubt this; in any event, there are always going to be cases when robots will run into trouble and men will have to get them out of it. Sooner or later there will be scientific and operational requirements for the human exploration of Jupiter; one day we may even wish to establish a permanent base there. This will demand some kind of gravity control – unless we breed a special class of Jovian colonists with the physiques of gorillas. (For more about the exploration of Jupiter, see Chapter 9.)

If this seems a little remote and fantastic, let me remind you that much closer to home there is an even more important example of a high-gravity planet which, perhaps less than fifty years from now, men may not be able to visit. That planet is our own Earth.

Without gravity control, we may be condemning the space-travellers and settlers of the future to perpetual exile. A man who has lived for a few years on the Moon, where he has known only a sixth of his terrestrial weight, would be a helpless cripple back on Earth. It might take him months of painful practice before he could walk again, and children born on the Moon (as they will be within another generation) might never be able to make the adjustment. One can think of few things more likely to breed bitterness and interplanetary discord than such gravitational expatriation.

To avoid this we need a really portable gravity-control unit, so compact that a man could strap it on his shoulders or round his waist. Indeed, it might even be a permanent part of his clothing, taken as much for granted as his wristwatch or his personal transceiver. He could use it to reduce his apparent weight down to zero, or to provide propulsion.

Anyone who is prepared to admit that gravity-control is possible at all should not boggle at this further development. Miniaturisation is one of the everyday miracles of our age, for better or for worse. The first thermonuclear bomb was as big as a house; today's economy-sized warheads are the size of waste-paper baskets – and from one of those baskets comes enough energy to carry the liner *Queen Elizabeth* to Mars. This everyday fact of modern missilry is, I submit, far more fantastic than the possibility of personal gravity-control.

The one-man gravitator, if it could be made cheaply enough, would be among the most revolutionary inventions of all times. Like birds and fish, we would have escaped from the tyranny of the vertical – we would have gained the freedom of the third dimension. In the city, no one would use the elevator if there was a convenient window. The degree of effortless mobility that would be attained would demand re-education to an entire new way of life – an almost avian order of existence. By the time it arrives, it will not be unfamiliar, for countless films of space-men in orbit will have made everyone accustomed to the idea of weightlessness, and eager to share its pleasures. Perhaps the levitator may do for the mountains what the Aqualung has done for the sea. The Sherpas and Alpine guides will, of course, be indignant; but progress is inexorable. It is only a matter of time before tourists are floating all over the Himalayas and the summit of Everest is as crowded as the sea-bed off Cannes or the Florida Keys.

Even if the extreme of personal, one-man levitation turns out to be impossible, we may still be able to build small vehicles in which we can drift slowly and silently (both are important) through the sky. The very idea of hovering in space was a fantasy a generation ago, until the helicopter opened our eyes. Now that experimental Ground Effect Machines are floating off in every direction on cushions of air, we will not be satisfied until we can roam at will over the face of the Earth, with a freedom that neither the automobile nor the aeroplane can ever give.

What the ultimate outcome of that freedom may be, no one can guess – but I have one final suggestion. When gravity can be controlled, our very homes may take to the air. Houses would no longer be rooted in a single spot; they would be far more mobile than today's trailers, free to move across land and sea, from continent to continent. And from climate to climate, for they would follow the sun with the changing seasons, or head into the mountains for the winter sports.

The first men were nomads; so may be the last, on an infinitely more advanced technical level. The completely mobile home would require, quite apart from its presently unattainable propulsion system, power, communication and other services equally beyond today's technology. But not, as we shall see, beyond tomorrow's.

This would mean the end of cities, which may well be doomed for other reasons. And it would mean the end of all geographical and regional loyalties, at least in the intense form that we know today. Man might become a wanderer over the face of the Earth – a gipsy driving a nuclear-powered caravan from oasis to oasis, across the deserts of the sky.

Yet when that day comes, he will not feel a rootless exile with no place to call his own. A globe that can be circumnavigated in ninety minutes can never again mean what it did to our ancestors. For those who come after us, the only true loneliness will lie between the stars. Wherever they may fly or float on this little Earth, they will always be at home.

SIX

THE QUEST FOR SPEED

This has often been called the Age of Speed, and for once the popular label is wholly correct. Never before has the velocity of transportation increased at such a staggering rate; it may never do so again.

Both these statements are borne out if we make a table showing all possible ranges or bands of speed, listed in orders of magnitude, and then note the decade at which each range was entered. The result is somewhat startling:

Band	*Speed range (mph)*	*Approximate date of entry to band*
1	1 – 10	*circa* 1,000,000 BC
2	10 – 100	ditto
3	100 – 1,000	1880
4	1,000 – 10,000	1950
5	10,000 – 100,000	1960
6	100,000 – 1,000,000	
7	1,000,000 – 10,000,000	
8	10,000,000 – 100,000,000	
9	100,000,000 – 1,000,000,000	

After spending the whole of prehistory and most of history in the first two speed bands, mankind shot through the third in a single lifetime. (I do not know the precise date at which a locomotive attained 100 mph, but it certainly became possible around 1880. The Empire State Express touched 112 mph on the New York Central line in 1893.) Even more astonishing is the fact that we passed through the whole of the fourth band in just over a decade; the period 1950 to 1960 covers (to the accuracy we are concerned with here) the huge jump from supersonic flight in the atmosphere to orbital flight outside it.

This, of course, was the result of the breakthrough in rocketry, which has produced what the mathematicians would call a discontinuity in the speed curve. We can hardly expect this acceleration to continue at the same rate; that would imply, for example, that we reached 100,000 mph well before 1970, which we didn't. Still more unlikely is the result obtained by continuing this naïve extrapolation – that we shall have reached Band Nine, and the ultimate speed limit of the Universe, before the year 2010.

For the final entry in the table is imaginary; Band Nine should really read '100,000,000-670,615,000 mph.' There is no such thing as a speed beyond this last figure; it is the velocity of light.

Let us ignore the question as to why this is a speed limit, and what – if anything – we can do about it, and concentrate on the lower end of the velocity spectrum. Bands One to Four cover the entire range of speeds necessary for all terrestrial purposes; indeed, many of us are content to remain in Band Three, and consider that today's jet liners already travel quite fast enough.

For ultra-high speed services, at several thousand miles an hour, it will be necessary to use rockets, and it seems unlikely that these can ever be economical on the basis of chemical propellants. Although we can now shoot a man around the world in ninety minutes, about a hundred tons of fuel has to be burned to do so. Even when rockets are fully developed, it is doubtful if the figure could be reduced to less than ten tons per passenger. This is some twenty times the already impressive half-ton of kerosene per passenger consumed by the big jets of today on a long-distance flight. (Of course, the rocket has to carry its oxygen as well – the penalty it must pay for travelling outside the atmosphere.)

Since attempts are now being made to develop the so-called Space Shuttle, which will carry a dozen or more passengers up to orbit, it might seem that this could lead to commercial rocket transportation – if only on a special premium-fare basis. If this seems a little unlikely, it is worth remembering that when the first jets started to fly, few people thought that the new engines could ever be used for anything except short-range, military applications. Yet within twenty years, they had transformed the airlines of the world, and shrunk our planet to less than half its previous size.

There are two lines of development that might make very high speed transportation an economic possibility. The first is a cheap, safe and clean nuclear propulsion system, which would greatly reduce the propellent load. Such a system is far beyond sight at the moment, because it could not be based upon fission – the only means currently available for releasing the energy of the atom. At the risk of making myself appear a reactionary old fogey, I do not believe that uranium and plutonium-fuelled devices should be allowed off the ground. Aircraft (here is a daring prediction) will always crash; it is bad enough to be sprayed by burning kerosene, but such disasters are at least local and temporary. Fall-out is neither.

The only mobile nuclear power-plants that can be tolerated in the air and nearby space must be free from radioactivity. We cannot build such systems at the moment, but we may be able to do so when we have achieved controlled thermonuclear reactions. Then, with a few pounds of lithium and heavy hydrogen as fuel, we will be able to fly substantial payloads round the world at up to orbital speed – 18,000 mph.

It has also been suggested – and this is one of those ideas that sound much too good to be true – that *fuelless* aircraft may be developed which can fly indefinitely in the upper atmosphere, powered by the natural sources of energy that exist there. These sources have already been tapped in a number of spectacular experiments. When sodium vapour is discharged from a rocket at the correct altitude, it triggers a reaction between the electrified atoms which lie on the boundaries between air and space. As a result a visible glow may spread across many miles of the sky. It is the energy of sunlight, collected by the atoms during the day and released when it receives the right stimulus.

Unfortunately, though the total amount of energy stored in the upper atmosphere is very large, it is also very dilute. Enormous volumes of rarefied gas would have to be collected and processed to give any useful result. *If* some kind of highspeed ramjet could scoop up the thin air, and release enough of its energy in the form of heat to produce an adequate thrust, then it could fly for ever with no expenditure of fuel. At the moment this seems unlikely, for the drag of the air-scoops would be much greater than the thrust that could be expected, but the idea should not be dismissed out of hand. A few decades ago we had no idea that such energy sources existed; there may be still more powerful ones yet to be discovered.

After all, there is nothing fundamentally absurd about the idea. We sailed the seas for thousands of years in fuelless ships, powered by the free energy of the winds. And that energy too, comes ultimately from the Sun.

However, even if fuel was free and unlimited, there would still be obstacles at *very* high flight speeds. Circus performers can tolerate being shot from cannon, but paying passengers object to high accelerations – and those are inevitable if we hope to attain really high speeds.

Even today, the take-off of a jet seems to keep one glued to the seat for a very long time – yet the acceleration involved is only a fraction of one gravity, and the speed eventually attained very modest compared with those we are now discussing.

Let us look at a few figures. An acceleration of ‘1-g’ means that *in each second* speed is increasing at the rate of 22 mph. At this rate it would take almost fourteen minutes to reach orbiting speed (18,000 mph), and during the whole of that time every passenger would feel that he had another man sitting on his lap. Then (on the longest possible flight, half the circumference of the Earth) there would be twenty minutes of completely weightless flight which would probably be even more disconcerting. And after that, another fourteen minutes, 1-g period, while the speed was being reduced to zero. At no time during the trip could anyone claim to be comfortable, and for the weightless portion of the flight, even the famous paper bag would be unusable. It might not be unfair to say that in round-the-world satellite transportation, half the time the toilet is out of reach, and the other half of the time it is out of order …

A close satellite orbit represents a kind of natural speed limit for travel round the Earth; once a body is established in it, it circles effortlessly at 18,000 mph, taking about 90 minutes per revolution. If we try to travel faster than this, we run into a new set of problems.

Everyone has experienced the ‘centrifugal force’ that results during a high-speed turn in a car or aeroplane. I use the quotation marks because what you feel then is not really a force at all, but the natural resentment of your body at being denied its inalienable right to continue travelling in a straight line at uniform velocity. The only force actually involved is that which has to be exerted by the seat of your vehicle to prevent you from doing this.

In flying round the world, or indeed during any movement on the face of the Earth, you are travelling in a circle of four thousand miles radius. At normal speeds, you never notice the negligible extra force needed to keep you attached to the ground; your weight is more than sufficient to provide it. At 18,000 mph, however, the inward or downward force required would exactly equal your weight. This, of course, is the condition for orbital flight; the Earth’s pull is just sufficient to hold on to a body moving around it at this speed.

If you travel *faster* than 18,000 mph, you must provide an additional downwards force to keep yourselves in orbit; Earth alone cannot do it. A situation thus arises – which the pioneers of aviation could scarcely have imagined when they were struggling to get off the ground – when a flying machine has to be *held down* to keep it at the correct altitude; without some tethering force, it will fly off into space, like a stone from a sling.

In the case of a vehicle circling the Earth at 25,000 mph, the extra force needed to keep it in orbit amounts to exactly one gravity. This might be provided by rockets driving the spacecraft towards the centre of the Earth with an acceleration of 1-g. Yet it would get no closer, and the only difference between this powered trajectory and a normal free satellite orbit is that it would be quicker – one hour instead of ninety minutes – and that the occupants of the vehicle would no longer be weightless. They would, in fact, appear to have their ordinary weight, but its direction would be reversed. ‘Down’ would be towards the stars; Earth would be hanging *above* the anxious astronauts, spinning on its axis every sixty minutes.

At greater speeds, still larger forces would have to be employed to keep the vehicle in its artificial orbit. Although there seems no possible use for such performances, which would require enormous amounts of energy, Man's love of record-breaking will presumably lead to ultra-high-speed circuits of the globe as soon as they become technically feasible. It is interesting to calculate the accelerations and times that such flights would involve; they are shown in the table below.

Velocity(mph)	***Time to orbit Earth (minutes)***	***Force experienced by passengers (gravities)***
18,000	90	0
25,000	60	1
31,000	48	2
36,000	42	3
40,000	37	4
44,000	34	5
60,000	25	10
100,000	15	30

Going round the world in less than thirty minutes is thus going to be a rugged proposition, as well as an expensive one. To do it in fifteen minutes, thirty gravities would have to be endured; this might be possible, if the occupant – who would not take much active interest in the proceedings, anyway – was totally immersed in water. I suggest, however, that such a performance would already have passed the limit of sanity. It is impracticable to make hair-pin turns round an astronomical pin-point like the Earth. Though men will travel round the world quite comfortably in eighty minutes, they will never do so in eight with any means of propulsion known today.

That last clause is not just a cautious afterthought. One day, I suggest, we will have methods of propulsion fundamentally different from any that have ever existed in the past. All known vehicles, without exception, accelerate their occupants by giving them a physical push which they feel through their boots or the seats of their pants. This is true of ox-carts and bicycles, of automobiles and rockets. That it need not always be true is suggested by the curious behaviour of gravitational fields.

When you fall freely under Earth's Gravity, you are increasing speed at the rate of 22 mph every second – but you do not *feel* anything at all. This would be true no matter how intense the gravity field; if you were dropped towards Jupiter, you would accelerate at 60 mph every second, for Jupiter's gravity is more than two and a half times Earth's. Near the Sun you would increase speed at the rate of 600 mph each second, and again you would feel no force acting upon you. There are stars – White Dwarfs – with gravity fields more than a thousand times as strong as Jupiter's; in the vicinity of such a star, you might add 100,000 mph to your speed *every second* without the slightest discomfort – until, of course, it was time to pull out …

The reason why you would experience no sensation or physical stress when being accelerated by a gravity field of *any* intensity is that it would act simultaneously upon every atom of your body. There would be no push transmitted through you layer by layer from the seat or the floor of the vehicle.

You have doubtless realized where this argument is leading. If, as I have suggested in the preceding chapter, we can ever control and direct gravity fields, this will give us far more than the ability to float around like clouds. It will enable us to accelerate in any direction, at a rate limited only by the power available, without feeling any mechanical stress or force. Such a method of propulsion might be called an 'inertialess drive' a term I have borrowed (with much else) from that veteran science-fiction writer, Dr E. E. Smith, though he used it in a somewhat different sense.

With such a drive, our vehicles could stop and start almost instantaneously. Perhaps even more important, they would be virtually crash-proof. Protected by their artificial gravity fields, they could run into each other at hundreds of miles an hour with no damage to anything except the nervous systems of their occupants. They could make right-angled turns or hair-pin bends, and though the reactions of a human pilot would be far too slow to operate them, men could ride in them with perfect safety and comfort. It might be arranged that, whatever acceleration they were actually undergoing, there would be a net or uncompensated force of just one gravity acting on the passengers, so that they would always feel their normal weight.

Though we can manage quite well, here on Earth, without such sophisticated methods of propulsion, they will ultimately become available as a by-product of space research. The rocket – let us face it – is not a practical method of getting around, as anyone who has ever stood in the open within a mile of a big static test will agree. We have to find something quieter, cleaner and more reliable – and something that will enable us to enter those now unattainable speed bands, 6, 7, 8, and finally 9.

For in the long run – and now I am looking perhaps centuries ahead – we will have used and discarded all the vehicles that we have employed in our climb up the velocity spectrum; the time will come when the ICBM appears no swifter than the Assyrian war-chariot. The three thousand years that lie between them is but a moment in the whole span of history, past and future – and for most of that span, men will be interested only in the two extreme ends of the speed band.

They will always, I hope, be content to wander about the world at two or three miles an hour, absorbing its beauty and its mystery. But when they are not doing this, they will be in a hurry: and then they will be satisfied with nothing short of that ultimate 670,615,000 mph.

Even this speed, of course, will be totally inadequate to meet the challenge of interstellar space, but as far as the Earth is concerned it would amount to instantaneous transportation. A light-wave could circle the globe in a seventh of a second; now let us see whether men can ever hope to do the same.

SEVEN

WORLD WITHOUT DISTANCE

The idea of instantaneous transport – 'teleportation' – is very old, and is embodied in many Eastern religions. There must be millions of people alive at this moment who believe that it has already been achieved, by Yogis and other adepts, through the exercise of sheer will-power. Anyone who has seen a good display of firewalking, as I have done,* must admit that the mind has almost unbelievable powers over matter – but in this particular case I beg to be sceptical.

One of the best proofs that mental teleportation is *not* possible was given, somewhat ironically, in a novel which described a society based upon it. Alfred Bester's *The Stars My Destination* opened with the interesting idea that a man threatened by sudden death might unconsciously and involuntarily teleport himself to safety. The fact that there is no authentic record of this happening, despite the millions of opportunities provided every year for putting the matter to the test, seems an excellent argument that it is not possible.

So let us consider teleportation in terms of known and foreseeable science, not wholly unknown and hypothetical mental powers. The only approach to the problem seems to be through electronics; we have learned to send sounds and images round the world at the velocity of light, so why not solid objects even men?

It is important to realize that the above sentence contains a fundamental mis-statement of fact, though I doubt if many people would spot it. We don't, by radio or TV or any other means, *send* sounds and images anywhere. They remain at their place of origin, and there, within a fraction of a second, they perish. What we do send is information – a description or plan which happens to be in the form of electrical waves – from which the original sights and sounds can be recreated.

In the case of sound, the problem is relatively simple and may now be regarded as solved, for with really good equipment it is impossible to distinguish the copy from the original. The task is simple (with due apologies to the several generations of scientists and audio engineers who have beaten out their brains over it) because sound is one-dimensional. That is to say, any sound – no matter how complex – can be represented as a quantity which at any instant has a *single* value.

It is, when one thinks about it, quite extraordinary that the massed resources of Wagner or Berlioz can be completely contained in a single wavering line etched on a disc of plastic. But this is true, if the line's excursions are sufficiently detailed. Since the human ear cannot perceive sounds of frequencies beyond 20,000 vibrations a second, this sets a limit to the amount of detail that a sound channel need carry – or its bandwidth, to use the technical term.

For vision, the situation is much more complicated, because we are now dealing with a two-dimensional pattern of light and shade. Whereas *at a single instant* a sound can possess just one level of loudness, a scene possesses thousands of variations in brilliance. All these have to be dealt with if we wish to transmit an image.

The television engineers solved the problem not by tackling it as a whole, but by carving it up into bits. In the TV camera a single scene is dissected into some quarter of a million picture elements, in much the same way that a photograph is screened by the block-maker for newspaper reproduction. What the camera does, in effect, is to carry out an incredibly rapid survey or sampling of the light values over the scene, and to report them to the receiving end of the equipment, which acts on the information and reproduces corresponding light values on the screen of the cathode-ray tube. At any given instant, a TV system is transmitting the image of a single point, but because a quarter of a million such images flash upon the screen in a fraction of a second we get the illusion of a complete picture. And because the whole process is repeated thirty times a second (twenty-five in countries with 50-cycle mains) the picture appears to be continuous and moving.

In a single second, therefore, an almost astronomical amount of information about light and shade has to be passed through a TV channel. Thirty times a quarter of a million means 7,500,000 separate signals a second; in practice a band-width of 4,000,000 cycles per second gives the adequate but hardly brilliant standard of definition provided by our domestic TV sets. If you think that is good, compare it for detail some day with a high-quality photograph of the same size as your screen.

Now let us do some technological day-dreaming, following in the footsteps of a great many science-fiction writers. (Perhaps starting with Conan Doyle; see one of his lesser-known Professor Challenger stories, *The Disintegration Machine,* published in the 1920s.) Imagine a super X-ray device that could scan a solid object, atom by atom, just as a TV camera scans a scene in the studio. It would produce a string of electrical impulses stating in effect: here is an atom of carbon; here a billionth of an inch further to the right is nothing; another billionth of an inch along is an atom of oxygen – and so on, until the entire object had been uniquely and explicitly described. Granted the possibility of such a device, it would not seem very much more difficult to reverse the process and build up, from the information transmitted, a duplicate of the original, identical with it in every way. We might call such a system a ‘matter transmitter’, but the term would be misleading. It would no more transmit matter than a TV station transmits light; it would transmit information from which a suitable supply of unorganized matter in the receiver could be arranged into the desired form. Yet the result could be, in effect, instantaneous transportation – or at least transportation at the speed of radio waves, which can circle the world in a seventh of a second.

The practical difficulties, however, are so gigantic that as soon as they are spelled out the whole idea seems absurd. One has only to compare the two entities involved; there is a universe of difference between a flat image of rather low definition, and a solid body with its infinite wealth and complexity of microscopic detail down to the very atom. Can any words or description span the gulf between the photograph of a man – and the man himself?

To indicate the nature of the problem, suppose you were asked to make an *exact* duplicate of New York City, down to every brick, pane of glass, kerbstone, doorknob, gas pipe, water main and piece of electric wiring. Especially the latter, for not only would the replica of the city have to be perfect in all its physical details, but its multitudinous power and telephone circuits would have to be carrying exactly the same currents as were those of the original at the moment of reproduction.

It would, obviously, take an army of architects and engineers to compile the necessary description of the city – to carry out the scanning process, if we revert to television parlance. And in that time the city would have changed so much that the job would have to be done over again; in fact, it could never be completed.

Yet a human being is not less than a million, and probably a million million, times more complex than such a simple artifact as New York City. (We will ignore for the moment the not-unimportant distinction that one object is a living, sentient creature, and the other is not.) We can assume, therefore, that the copying process would take correspondingly longer. If it took a year to scan New York – a highly optimistic assumption – then to carry out the same process for a single human being would probably require all the time that is available before the stars go out. And to pass the resultant information through any communications channel would probably take about as long.

We can see this merely by looking at the figures involved. There are, very roughly, 5×10^{27} atoms in a human body, as compared with the 250,000 picture elements in a TV image. It takes a TV channel a thirtieth of a second to handle these; simple arithmetic shows that a channel of the same capacity would take about 2×10^{13}, or 20,000,000,000,000 years, to transmit a ‘matter image’ from one spot to another. It would be quicker to walk.

Though the above analysis is childishly naive (any communications engineer can think of ways of knocking five or six zeros from this figure), it does indicate the magnitude of the problem, and the impossibility of solving it with presently imaginable techniques. It does not prove that it can never be done, but merely that it is far beyond the scope of today’s science. For us even to attempt it would be as if Leonardo da Vinci tried to build a purely mechanical (ie non-electric) television system.

This analogy is such a close one that it is worth developing it a little further. How *would* Leonardo have tackled the problem of sending a high-definition (250,000 picture elements) image from one point to another?

You will be surprised to find that he could have done it, though it would have been a pointless *tour-de-force.* This is how he might have proceeded:

A large lens would have projected the image to be transmitted into a darkened room, on to a white screen. (The camera obscura, which does just this, was quite familiar to Leonardo, who described it in his notebooks.)

Over the picture would be laid a rectangular grid or sieve, with five hundred wires to a side, so that the image was divided into 250,000 separate elements. Each wire would be numbered, so that a pair of three-figure co-ordinates, such as 123:456, would identify every point in the field.

It would then be necessary for some sharp-eyed individual to examine the picture element by element and say ‘Yes’ or ‘No’ according to whether or not that element was illuminated. (If you imagine yourself going over a newspaper block with a magnifying glass, you have a very good idea of the procedure.) If ‘0’ meant darkness and ‘1’ light, the whole picture could be described, within these limits of definition, by a series of 7-figure numbers. ‘1:111:111’ would mean that the element on the extreme top left was illuminated; ‘0:500:500’, that the last one on the bottom right was dark.

Now Leonardo has the problem of transmitting this series of a 250,000 seven-figure number to a distant point. That could be done in many ways – semaphores, flashing lights and so on. At the receiving end, the image could be synthesized by putting black dots in the appropriate places on a blank 500 X 500 grid, or by having a quarter of a million tiny shutters that could be opened and closed in front of a white sheet, or in a dozen other ways.

And how long would all this take? The bottle-neck would probably be the semaphore; Leonardo would be very lucky to send one digit a second, and he has 1,750,000 to cope with. So it would require about twenty days, not to mention a fantastic amount of effort and eyestrain, to transmit this single image.

Leonardo could cut down the time, at the cost of mechanical complication, by having a number of men working in parallel, but he would soon reach the point of diminishing returns. Twenty operators, all scanning the image and sending their information over separate semaphores, would certainly get in each others' way; even so, they could not complete the task in less than a day. *That it could ever be performed in a thirtieth of a second would have seemed to Leonardo, perhaps the most far-seeing man who ever lived, an absolute and unquestionable impossibility.* Yet five hundred years after his birth, thanks to electronics, it was happening in most of the homes in the civilized world.

It may well be that there are technologies as much beyond electronics as that surpasses the clumsy machinery of the Middle Ages; within the frameworks of such technologies, even the scanning, transmission and reconstruction of an object as complex as a human being may prove to be possible – and in a reasonably short period of time, say a matter of a few minutes. Yet even this does not mean that we will ever be able to send a living man, with his thoughts, memories and his unique feeling of identity, over the equivalent of a radio circuit. For a man is more than the sum of his atoms; he is at least that, plus all the unimaginably large number of energy states and special configurations in which those atoms happen to be at a given moment of time. Modern physics (especially Heisenberg's Uncertainty Principle) maintains that it is fundamentally impossible to measure all those states and configurations with absolute accuracy – that, in fact, the very conception is meaningless. Like a carbon copy, the duplicate would have to have some degree of blurring, from the nature of things. The blurring might be too small to matter (like the noise on a high quality tape-recording) or it might be so bad that the copy would be unrecognizable, like a newspaper block that has been screened too many times. Producers of horror movies, please note.

I make no apologies for the purely mechanistic approach in this discussion; we have enough technical problems already on our hands without bringing in such indefinables as the soul and the spirit. It may well be argued that even if we could reproduce a man down to his ultimate atoms, the result would not be a living creature – or if it was, not the creature we started with. Yet such a reproduction would be a *minimum* requirement; we might have to do much more, but we would certainly have to do that.

There is one philosophical point, however, which I cannot ignore and which has doubtless already occurred to you. If this type of transportation is possible at all, it would have some hair-raising consequences.

For a matter transmitter is not ‘merely’ a transmitter; it is potentially a multiplier, which could turn out any number of copies indistinguishable from the original. There would be as many copies as there were receiving sets; or perhaps the ‘signal’ could be recorded and played back over and over again through the same receiver. In this connection, it is relevant to point out that the cost of the raw materials in a human body is a couple of dollars …

One day all manufacturing processes will be based on this idea, which is certainly practical with simple, inanimate objects and even fairly complex but non-living materials. We do not object to thousands of identical ashtrays or teacups or automobiles; but society would collapse into a nightmare confusion if confronted with hundreds of men each claiming – correctly – to be the same person. Even two or three replicas of a key statesman could result in chaos, and the possibilities for crime, intrigue and warfare are so appalling that here would undoubtedly be an invention far more dangerous than any atom bomb. Yet the fact that a thing is horrible does not make it impossible, as the inhabitants of Hiroshima discovered. We may well hope that a matter transmitter/duplicator that can handle human beings will always remain beyond achievement, but I suspect that some day we will have to face the problems it raises.

I also suspect that the brute-force, television-type approach just outlined will not be the best way of achieving instantaneous transportation; the real answer (if indeed there is one) may be very much more subtle. It may involve the very nature of Space itself.

Space, someone once remarked with great acuteness, is what stops everything from being in the same place. But suppose we *want* two things to be in the same place – or, better still, two places to be in the same place?

The idea that Space is fixed, invariant and absolute has taken a beating during the last fifty years, thanks largely to Einstein. But even before the Theory of Relativity made us take a keen, hard look at ideas that had always seemed common sense, the concept of classical or Euclidean space had been challenged by a number of philosophers and mathematicians. (Especially Nikolai Ivanovich Lobachevski, 1793-1856, whose indignant ghost is now waiting to have a few words with Mr Tom Lehrer.)

There are at least two ways in which Space may have properties more complex than those described in the geometry books that most of us vaguely remember from our schooldays. It can disobey the fundamental axioms of Euclid; or it can have more than three dimensions. Much more frightful possibilities have been imagined by modern geometricians – whose motto is, ‘If it can be visualized, it isn’t geometry’ – but we can thankfully disregard these.

The Fourth Dimension has been out of fashion for quite a while: it was popular round the turn of the century, and perhaps it may come back into style some day. There is nothing particularly difficult about the idea that there could be something as much ‘higher’ than the cube as that is higher than the square, and it is quite easy to work out the properties of four or indeed n-dimensional figures, by analogy with those of lower dimensions; we will be doing this in Chapter 14.

Though I am willing (well, fairly willing) to stand correction on this matter, I do not think that multi-dimensional *Euclidean* space allows the possibility of short-cuts between points in our familiar three-dimensional world. Two points with a certain separation in 3-space will still have at least that separation in any higher space. If, however, we imagine that space can be bent or curved, so that the axioms of Euclid no longer apply, then some interesting possibilities arise.

Once again, these can be appreciated only by analogy. Think of that familiar but mysterious figure, the Möbius strip – formed by gluing two ends of a strip of paper together after giving it a half-twist. As is well known, the result is a ‘single-sided surface’, a fact which you can prove very easily by running your finger along it. (At this point I suggest that you make a Möbius strip, which will take you about thirty seconds and is well worth the effort.)

Take hold of the strip between thumb and forefinger. With a pencil, you can trace a continuous line from your thumb to your forefinger by going once around the strip. (Or is it only half a circuit? But that’s another story.) If you were a ‘Flatlander’ able to travel only on the surface of the strip, this might be a very considerable distance.

On the other hand, if you could move through the thickness of the paper – the direct line between the thumb and forefinger – the distance would be very short. Instead of ten inches, it might be a few thousandths of an inch.

This simple little experiment suggests some very complex possibilities. Types of space can be imagined in which two points A and B might be a long way apart in one direction, but quite close in another.

Because we can imagine this situation, it does not mean that it is physically realizable, or that there are ‘holes in space’ through which we can take short cuts across the Universe. We believe, however, that the geometry of space is variable – a fact which would have seemed absurd to all the mathematicians who lived in the 2,000-year-long shadow of Euclid. Space can be altered by the presence of gravitational fields – though this may be putting the cart before the horse; gravitational ‘fields’, so-called, are the result, not the cause, of curvatures in space.

One day, perhaps, we may gain control of fields or forces which will allow us to alter the structure of space in useful manners, possibly tying it into pretzel-shaped knots with properties even more remarkable than those of the Möbius Strip. The old science-fiction idea of the ‘space-warp’ may not be pure fantasy; one day it may be part of our normal lives, enabling us to step from one continent to another (or one world to another?) as easily as from one room to the next.

Or the answer may come in some totally novel and unexpected way, as it has done so often in the past. We must assume that speeds of transportation will continue to increase to the limits of the technically feasible, and we are in no position to say where those limits may lie. Signals can travel at the speed of light, and material objects at not far short of it. Some day we may do the same.

There is, however, one trend which may work against the establishment of a virtually instantaneous global transportation system. As communications improve, until *all* the senses – and not merely vision and hearing – can be projected anywhere on the face of the Earth, men will have less and less incentive to travel. This situation was envisaged half a century ago by E. M. Forster in his famous short story, *The Machine Stops,* where he pictured our remote descendants as living in single cells, scarcely ever leaving them, but being able to establish instant TV contact with anyone else on Earth, wherever he might be.

In his own lifetime Forster saw TV perfected far beyond his imaginings of three decades ago, and his vision of the future may be, in its essentials, not so far from the truth. Telecommunication and transportation are opposing forces, which so far have always struck a balance. If the first should ever win, the world of Forster’s story would be the result.

On the other hand, a transportation breakthrough like that which the rise of electronics brought to communications would lead to a world of limitless and effortless mobility. Gone would be all the barriers of distance that once sundered man from man, country from country. The transformation that the telephone has wrought in business and social life would be as nothing to that which the ‘teleporter’ would bring to the whole of our civilization. To dismiss in a single sentence a possibility that would revolutionize (if not abolish) most of commerce and industry – imagine what would happen if we could transmit raw materials or manufactured goods instantaneously round the face of the planet! This would be billions of times less difficult, technically, than transmitting such fragile and complex entities as human beings, and I have little doubt that it will be achieved within a few centuries.

Through all the ages, Man has fought against two great enemies – Time and Space. Time he may never wholly conquer, and the sheer immensity of Space may also defeat him when he has ventured more than a few light-years from the Sun. Yet on this little Earth at least, he may one day claim a final victory.

I do not know *how* it will be done, and perhaps everything I have said may merely have convinced you that it is impossible. But I believe that the time will come when we can move from Pole to Pole within the throb of a single heartbeat.

It will be one of history’s little jokes if, when we attain this power, we are no longer interested in using it.

EIGHT

ROCKET TO THE RENAISSANCE

Four and a half centuries ago, European civilization started expanding into the unknown, in a slow but irresistible explosion fuelled by the energies of the Renaissance. After a thousand years of huddling round the Mediterranean, Western man had discovered a new frontier beyond the sea. We know the very day when he found it – and the day when he lost it. The American frontier opened on October 12th, 1492; it closed on May 10th 1869, when the last spike was driven into the trans-continental railroad.

In all the long history of Man, ours is the first age with no new frontiers on land or sea, and many of our troubles stem from this fact. It is true that, even now, there are vast areas of the Earth still unexploited and even unexplored, but dealing with them will only be a mopping-up operation. Though the oceans will keep us busy for centuries to come, the count-down started even for them, when the bathyscope *Trieste* descended into the ultimate deep of the Marianas Trench.

There are no more undiscovered continents; set out towards any horizon, and on its other side you will find someone already waiting to check your visa and your vaccination certificate …

This loss of the unknown has been a bitter blow to all romantics and adventurers. In the words of Walter Prescott Webb, the historian of the American South-West: ‘The end of an age is always touched with sadness … The people are going to miss the frontier more than words can express. For centuries they heard its call, listened to its promise, and bet their lives and fortunes on its outcome. It calls no more …’

Professor Webb’s lament, I am glad to say, is a few million years premature. Even while he was writing it in the small state of Texas, not a thousand miles to his west the vapour trails above White Sands were pointing to a frontier unimaginably vaster than any that our world has ever known – the frontier of Space.

The road to the stars has been discovered none too soon. Civilization cannot exist without new frontiers; it needs them both physically and spiritually. The physical need is obvious – new lands, new resources, new materials. The spiritual need is less apparent, but in the long run it is more important. We do not live by bread alone; we need adventure, variety, novelty, romance. As the psychologists have shown by their sensory deprivation experiments, a man goes swiftly mad if he is isolated in a silent, darkened room, cut off completely from the external world. What is true of individuals is also true of societies; they too can become insane without sufficient stimulus.

It may seem over-optimistic to claim that Man's forthcoming escape from Earth, and the crossing of interplanetary space, will trigger a new Renaissance and break the pattern into which our society, and our arts, must otherwise freeze. Yet this is exactly what I propose to do; first, however, it is necessary to demolish some common misconceptions.

The Space Frontier is infinite, beyond all possibility of exhaustion; but the opportunity and the challenge it presents are both totally different from any that we have met on our own world in the past. All the moons and planets of this Solar System are strange, hostile places that may never harbour more than a few thousand human inhabitants, who will be at least as carefully handpicked as the population of Los Alamos. The age of mass colonization has gone forever. Space has room for many things, but not for 'your tired, your poor, your huddled masses yearning to breathe free' … Any Statue of Liberty on Martian soil will have inscribed upon its base: 'Give me your nuclear physicists, your chemical engineers, your biologists and mathematicians.' The immigrants of the twenty-first century will have much more in common with those of the seventeenth century than the nineteenth. For the *Mayflower*, it is worth remembering, was loaded to the scuppers with eggheads.

The often-expressed idea that the planets can solve the problem of over-population is thus a complete fallacy. Humanity is now increasing at the rate of over 100,000, *a day*, and no conceivable 'space-lift' could make serious inroads into this appalling figure.

With present techniques, the combined military budgets of all nations might just about suffice to land ten men on the Moon every day. Yet even if space transportation were free, instead of being fabulously expensive, that would scarcely help matters – for there is not a single planet upon which men could live and work without elaborate mechanical aids. On all of them we shall need the paraphernalia of space-suits, synthetic air factories, pressure-domes, totally-enclosed hydroponic farms. One day our lunar and Martian colonies will be self-supporting, but if we are looking for living room for our surplus population, it would be far cheaper to find it in the Antarctic – or even on the bottom of the Atlantic Ocean.

No: the population battle must be fought and won here on Earth, and the longer we postpone the inevitable conflict the more horrifying the weapons that will be needed for victory. (Compulsory abortion and infanticide, and anti-heterosexual legislation – with its reverse – may be some of the milder expedients.) Yet though the planets cannot save us, this is a matter in which logic may not count. The weight of increasing numbers – the suffocating sense of pressure as the walls of the ant-heap crowd ever closer – will help to power Man's drive into space, even if no more than a millionth of humanity can ever go there.

Perhaps the battle is already lost, here on this planet. As Sir George Darwin has suggested in his depressing little book, *The Next Million Years,* ours may be a Golden Age, compared with the endless vistas of famine and poverty that must follow when the billions of the future fight over Earth's waning resources. If this is true, it is all the more vital that we establish self-sustaining colonies on the planets. They may have a chance of surviving, and preserving something of our culture, even if civilization breaks down completely on the mother world.

Though the planets can give no physical relief to the congested and impoverished Earth, their intellectual and emotional contribution may be enormous. The discoveries of the first expeditions, the struggles of the pioneers to establish themselves on other worlds – these will inspire a feeling of purpose and achievement among the stay-at-homes. They will know, as they watch their TV screens, that History with a capital H is starting again. The sense of wonder, which we have almost lost, will return to life; and so will the spirit of adventure.

It is difficult to overrate the importance of this – though it is easy to poke fun at it by making cynical remarks about 'escapism'. Only a few people can be pioneers or discoverers, but everyone who is even half alive occasionally feels the need for adventure and excitement. If you require proof of this, look at the countless horse-operas now galloping across the ether. The myth of a West that never was has been created to fill the vacuum in our modern lives, and it fills it well. Sooner or later, however, one tires of myths (many of us have long since tired of *this* one) and then it is time to seek new territory. There is a poignant symbolism in the fact that the giant rockets now stand poised on the edge of the Pacific, where the covered wagons halted only two lifetimes ago.

Already, a slow but profound reorientation of our culture is under way, as men's thoughts become polarized towards space. Even before the first living creature left Earth's atmosphere, the process had started in the most influential area – the nursery. Space-toys have been commonplace for years; so have cartoons and 'Take me to your leader' jokes that would have been incomprehensible only a decade ago. Increasing awareness of the Universe has even, alas, contributed to our psychopathology. A fascinating parallel could be drawn between the Flying Saucer cults and the witchcraft mania of the seventeenth century. The mentalities involved are the same, and I hereby present the notion to any would-be Ph D in search of a thesis.

As the exploration of the Solar System proceeds, human society will become more and more permeated with the ideas, discoveries and experiences of astronautics. They will have their greatest effect, of course, upon the men and women who actually go out into space to establish either temporary bases or permanent colonies on the planets. Because we do not know what they will encounter, it is scarcely profitable to speculate about the societies that may evolve, a hundred or a thousand years from now, upon the Moon, Mars, Venus, Titan and the other major solid bodies of the Solar System. (We can write off the giant planets, Jupiter, Saturn, Uranus and Neptune, which have no stable surfaces.) The outcome of our ventures in space must await the verdict of history; certainly we will witness, on a scale their author never imagined, the testing of Toynbee’s laws of ‘Challenge and response’. In this context, these words from the abridged *Study of History* are well worth pondering: ‘Affiliated civilizations … produce their most striking early manifestations in places outside the area occupied by the “parent” civilization. The superiority of the response evoked by new ground is most strikingly illustrated when the new ground has to be reached by a sea-passage … Peoples occupying frontier positions, exposed to constant attack, achieve a more brilliant development than their neighbours in more sheltered positions.’

Alter ‘sea’ to ‘space’ and the analogy is obvious; as for the ‘constant attack’, Nature will provide this more competently than any merely human adversaries. Ellsworth Huntington has summed up the same idea in a memorable phrase, pointing out that the march of civilization has been ‘coldward and stormward’. The time has come now to pit our skill and resolution against climates and environments more hostile than any that this earth can show.

As has happened so often in the past, the challenge may be too great. We may establish colonies on the planets, but they may be unable to maintain themselves at more than a marginal level of existence, with no energy left over to spark any cultural achievements. History has one parallel as striking as it is ominous, for long ago the Polynesians achieved a technical *tour-de-force* which may well be compared with the conquest of space. By establishing regular maritime traffic across the greatest of oceans, writes Toynbee, they ‘won their footing on the specks of dry land which are scattered through the watery wilderness of the Pacific almost as sparsely as the stars are scattered through space’. But the effort defeated them at last, and they relapsed into primitive life. We might never have known of their astonishing achievement had it not left, on Easter Island, a memorial that can hardly be overlooked. There may be many Easter Islands of space in the aeons to come – abandoned planets littered not with monoliths but with the equally enigmatic debris of other defeated technologies.

Whatever the eventual outcome of our exploration of space; we can be reasonably certain of some immediate benefits – and I am deliberately ignoring such ‘practical’ returns as the multi-billion dollar improvements in weather forecasting and communications, which may in themselves put space-travel on a paying basis. The creation of wealth is certainly not to be despised, but in the long run the only human activities really worth while are the search of knowledge, and the creation of beauty. This is beyond argument; the only point of debate is which comes first.

Only a small part of mankind will ever be thrilled to discover the electron density around the Moon, the precise composition of the Jovian atmosphere, or the strength of Mercury’s magnetic field. Though the existence of whole nations may one day be determined by such facts, and others still more esoteric, these are matters which concern the mind, and not the heart. Civilizations are respected for their intellectual achievements; they are loved – or despised – for their works of art. Can we even guess, today, what art will come from Space?

Let us first consider literature, for the trajectory of any civilisation is most accurately traced by its writers. To quote again from Professor Webb’s *The Great Frontier:* ‘We find that in general each nation’s Golden Age coincides more or less with that nation’s supremacy in frontier activity … It seems that as the frontier boom got under way in any country, the literary genius of that nation was liberated …’

The writer cannot escape from his environment, however hard he tries. (If Lewis Carroll had lived today, he would have given us not *Alice*, but *Lolita.)* When the frontier is open we have Homer and Shakespeare – or, to choose less Olympian examples nearer to our own age, Melville, Whitman and Mark Twain. When it is closed, the time has come for Tennessee Williams and the Beatniks – and for Proust, whose horizon was a cork-lined room.

It is too naïve to imagine that astronautics will restore the epic and the saga in anything like their original forms; spaceflight will be too well documented, and Homer started off with the great advantage of being untrammelled by too many facts. But surely the discoveries and adventures, the triumphs and inevitable tragedies that must accompany Man’s drive towards the stars will one day inspire a new heroic literature, and bring forth latter-day equivalents of *The Golden Fleece, Gulliver’s Travels, Moby Dick, Robinson Crusoe* or *The Ancient Mariner*.

The fact that the conquest of the air has done nothing of the sort must not be allowed to confuse the issue. It is true that the literature of flight is very sparse

(Lindbergh and Saint-Exupery are almost the only examples that come to mind), but the reason is obvious. The aviator spends only a few hours in his element, and travels to places that are already known. (In the few cases where he flies over unexplored territory, he is seldom able to land there.) The space-voyager, on the other hand, may be on his way for weeks, months or years, to regions that no man has ever seen save dimly through a telescope. Space-flight has, therefore, very little in common with aviation; it is much closer in spirit to ocean voyaging, which has inspired so many of our greatest works of literature.

It is perhaps too early to speculate about the impact of space-flight on music and the visual arts. Here again one can only hope – and hope is certainly needed, when one looks at the canvasses upon which the contemporary painters all too accurately express their psyches. The prospect for modern music is a little more favourable; now that electronic computers have been taught to compose it, we may confidently expect that before long some of them will learn to enjoy it, thus saving us the trouble.

Maybe these ancient art-forms have come to the end of the line, and the still unimaginable experiences that await us beyond the atmosphere will inspire new forms of expression. The low or non-existent gravity, for example, will certainly give rise to a strange, other-worldly architecture, fragile and delicate as a dream. And what, I wonder, will *Swan Lake* be like on Mars, when the dancers have only a third of their terrestrial weight – or on the Moon, where they will have merely a sixth?

The complete absence of gravity – a sensation which no human being has ever experienced since the beginning of the world, yet which is mysteriously familiar in dreams – will have a profound impact upon every type of human activity. It will make possible a whole constellation of new sports and games, and transform many existing ones. This final prediction we can make with confidence, if some impatience; weightlessness will open up novel and hitherto unsuspected realms of erotica. And about time too.

All our aesthetic ideas and standards are derived from the natural world around us, and it may well turn out that many of them are peculiar to Earth. No other planet has blue skies and seas, green grass, hills softly rounded by erosion, rivers and waterfalls, a single brilliant moon. Nowhere in space will we rest our eyes upon the familiar shapes of trees and plants, or any of the animals who share our world. Whatever life we meet will be as strange and alien as the nightmare creatures of the ocean abyss, or of the insect empire whose horrors are normally hidden from us by their microscopic scale. It is even possible that the physical environments of the other planets may turn out to be unbearably hideous; it is equally possible that they lead us to new and more universal ideas of beauty, less limited by our earthbound upbringing.

The existence of extra-terrestrial life is, of course, the greatest of the many unknowns awaiting us on the planets. We are now at the point of discovering whether there is vegetation on Mars; the Mariner and Viking missions should settle this matter one way or the other. On this strange little world, the struggle for existence may have led to some weird results. We had better be careful when we land.

Where there is vegetation, there may be higher forms of life; given sufficient time, Nature explores all possibilities. Mars has had plenty of time, so those parasites on the vegetable kingdom known as animals may have evolved there. They will be very peculiar animals, for they will have no lungs. There is not much purpose in breathing when the atmosphere is practically devoid of oxygen.

Beyond this, biological speculation is not only pointless but distinctly unwise, since we will know the truth within another ten or twenty years – and perhaps much sooner. The time is fast approaching when we will discover, once and for all, whether the Martians exist.

Contact with a contemporary, non-human, civilization will be the most exciting thing that has ever happened to our race; the possibilities for good and evil are endless. Within a decade or so, some of the classic themes of science-fiction may enter the realm of practical politics. It is much more likely, however, that if Mars ever has produced intelligent life, we have missed it by geological ages. Since all the planets have been in existence for at least five *billion* years, the probability of cultures flourishing on two of them at the same time must be extremely small.

Yet the impact of even an extinct civilization could be overwhelming; the European Renaissance, remember, was triggered by the rediscovery of a culture that flourished more than a thousand years earlier. When our archaeologists reach Mars, they may find waiting for us a heritage as great as that which we owe to Greece and Rome. The Chinese scholar, Hu Shih, has remarked: ‘Contact with strange civilizations brings new standards of value, with which the native culture is re-examined and re-evaluated, and conscious reformation and regeneration are the natural outcome.’ Hu Shih was speaking of the Chinese literary renaissance, *circa* 1915. Perhaps these words may apply to the Terrestrial Renaissance, a century hence.

We should not, however, pin too much hope on Mars, or even upon any of the worlds of this Solar System. If intelligent life exists elsewhere in the Universe, we may have to seek it upon the planets of other suns. They are separated from us by a gulf millions – repeat, *millions* – of times greater than that dividing us from our next-door neighbours, Mars and Venus. Until a few years ago, even the most optimistic scientists thought it impossible that we could ever span this frightful abyss, which light itself takes years to cross at a tireless 670,615,000 miles an hour. Yet now, by one of the most extraordinary and unexpected breakthroughs in the history of technology, there is a good chance that we may contact intelligence *outside* the Solar System before we discover the humblest mosses or lichens inside it.

This breakthrough has been in electronics. It now appears that by far the greater part of our exploration of space will be by radio. It can put us in touch with worlds that we can never visit – even with worlds that have long since ceased to exist. The radio telescope, and not the rocket, may be the instrument that first establishes contact with intelligence beyond the Earth.

A few decades ago, this idea would have seemed absurd. But now we have receivers of such sensitivity, and antennas of such enormous size, that we can hope to pick up radio signals from the nearer stars – if there is anyone out there to send them. The search for such signals began early in 1960 at the National Radio Astronomy Observatory, Greenbank, Virginia, and has since been continued by other observatories – especially in the Soviet Union. This is perhaps the most momentous quest upon which men have ever embarked; sooner or later, it will be successful.

From the background of cosmic noise, the hiss and crackle of exploding stars and colliding galaxies, we will some day filter out the faint, rhythmic pulses which are the voices of intelligence. At first we will know only (only!) that there are other minds than ours in the Universe; later we will learn to interpret these signals. Some of them, it is fair to assume, will carry images – the equivalent of picture-telegraphy, or even television. It will be fairly easy to deduce the coding and reconstruct these images. One day, perhaps not far in the future, some cathode-ray screen will show pictures from another world.

Let me repeat that this is no fantasy. At this very moment millions of dollars' worth of electronic equipment are engaged upon the search. It may not be successful until the radio astronomers can get into orbit, where they can build antennae miles across and can screen them from the incessant din of Earth. We may have to wait ten – or a hundred – years for the first results; no matter. The point I wish to make is that even if we can never leave the Solar System in a physical sense, we may yet learn something about the civilizations circling other stars – any they may learn about us. For as soon as we detect messages from space, we will attempt to answer them.

There are fascinating and endless grounds for speculation here; let us consider just a few of the possibilities. (And in a universe of a hundred thousand million suns, almost any possibility is a certainty – somewhere, some time.) We have known radio for barely a lifetime, and TV for barely a generation; all our techniques of electronic communication must be incredibly primitive. Yet even now, if put to it, we could send all that is best in our culture pulsing across the light-years. (Perhaps we have already sent much of the worst.)

Music, painting, sculpture, even architecture present no problems, since they involve easily transmitted patterns. Literature raises much greater difficulties; it could be *transmitted*, but could it be *communicated*, even if it were preceded by the most elaborate radio equivalent of the Rosetta Stone? The fact that here on Earth many writers, and most poets, have ceased to communicate with their fellow beings indicates a few of the difficulties.

But something must be lost in any contact between cultures; what is gained is far more important. In the ages to come we may lock minds with many strange beings, and study with incredulity, delight or horror, civilizations that may be older than our Earth. Some of them will have ceased to exist during the centuries that their signals have been crossing space. The radio astronomers will thus be the true interplanetary archaeologists, reading inscriptions and examining works of art whose creators passed away before the building of the pyramids. Even this is a modest estimate; a radio wave arriving now from a star at the heart of the Milky Way (the stellar whirlpool in whose lonely outer reaches our sun gyrates) must have started its journey around 25,000 BC. When Toynbee defined Renaissances as ‘contacts between civilizations in time’ he could hardly have guessed that this phrase might one day have an astronomical application.

Radio-prehistory – electronic archaeology – may have consequences at least as great as the classical studies of the past. The races whose messages we interpret and whose images we reconstruct will obviously be of a very high order, and the impact of their art and technology upon our own culture will be enormous. The rediscovery of Greek and Latin literature in the fifteenth century, the avalanche of knowledge when the Manhattan Project was revealed, the glories uncovered at the opening of Tutankhamen’s Tomb, the excavation of Troy, the publication of the *Principia* and *The Origin of Species* – these widely dissimilar examples may hint at the stimulus and excitement that may come when we have learned to interpret the messages which for ages have fallen upon the heedless Earth.

Not all of these messages – not many, perhaps – will bring us comfort. The proof, which is now only a matter of time, that this young species of ours is low in the scale of cosmic intelligence, will be a shattering blow to our pride. Few of our current religions can be expected to survive it, contrary to the optimistic forecasts from certain quarters. The assertion that ‘God made Man in His own image’, is ticking like a time-bomb in the foundations of Christianity. As the hierarchy of the universe is slowly disclosed to us, we will have to face this chilling fact: if there are any gods whose chief concern is Man, they cannot be very important gods.

The examples I have given, and the possibilities I have outlined, should be enough to prove that there is rather more to space-exploration than shooting men into orbit, or taking photos of the far side of the Moon. These are merely the trivial preliminaries to the age of discovery that is now about to dawn. Though that age will provide the necessary ingredients for a Renaissance, we cannot be sure that one will follow. The present situation has no exact parallel in the history of mankind; the past can provide hints, but no firm guidance. To find anything comparable with our forthcoming ventures into space, we must go back far beyond Columbus, far beyond Odysseus – far, indeed, beyond the first ape-man. We must contemplate the moment, now irrevocably lost in the mists of time, when the ancestor of all of us came crawling out of the sea.

For this is where life began, and where most of this planet's life remains to this day, trapped in a meaningless cycle of birth and death. Only the creatures who dared the hostile, alien land were able to develop intelligence; now that intelligence is about to face a still greater challenge. It may even be that this beautiful Earth of ours is no more than a brief resting-place between the sea of salt where we were born, and the sea of stars on which we must venture forth.

There are, of course, many who would deny this, with varying degrees of indignation or even fear. Consider the following extract from Lewis Mumford's *The Transformation of Man*: 'Post-historic man's starvation of life would reach its culminating point in interplanetary travel … Under such conditions, life would again narrow down to the physiological functions of breathing, eating, and excretion … By comparison, the Egyptian cult of the dead was overflowing with vitality; from a mummy in his tomb one can still gather more of the attributes of a full human being than from a spaceman.'

I am afraid that Professor Mumford's view of space-travel is slightly myopic, and conditioned by the present primitive state of the art. But when he also writes: 'No one can pretend … that existence on a space satellite or on the barren face of the moon would bear any resemblance to human life' he may well be expressing a truth he had not intended. 'Existence on dry land', the more conservative fish may have said to their amphibious relatives, a billion years ago, 'will bear no resemblance to piscatorial life. We will stay where we are.'

They did. They are still fish.

It can hardly be denied that Professor Mumford's view is held, consciously or otherwise, by a very large number of Americans, particularly those older and more influential ones who determine policy. This prompts certain sombre conclusions; perhaps the United States has already suffered that failure of nerve which is one of the first signs that a civilization has contracted out from the future.

The whole structure of American society may well be unfitted for the effort that the conquest of space demands. No nation can afford to divert its ablest men into such essentially non-creative, and occasionally parasitic, occupations as law, advertising and banking. Nor can it afford to squander indefinitely the technical manpower it does possess. Some years ago *Life* published a photograph which was a horrifying social document; it showed 7,000 engineers massed behind the car that their combined efforts, plus several hundred million dollars, had just produced. The time may well come when the United States, if it wishes to stay in space, will have to consider freezing automobile design for a few years – or better still, reverting to the last models that were any good, which some authorities date around 1954.

It does not necessarily follow that the Soviet Union can do much better; if it expects to master space by its own efforts, it will soon find that it has bitten off more than it can chew. The combined resources of mankind are inadequate for the task, and always will be. We may regard with some amusement the Russians' attempts to 'go it alone', and should be patient with their quaint old-fashioned flag-waving as they plant the hammer and sickle on the Moon. All such flurries of patriotism will be necessarily short-lived. The Russians themselves destoyed the concept of nationality when they sent Sputnik I flashing across a hundred frontiers. But because this is perfectly obvious, it will be some little time before everyone sees it, and all governments realize that the only runner in the much-vaunted space race is – Man.

Despite the perils and problems of our times, we should be glad that we are living in this age. Every civilization is like a surf-rider, carried forward on the crest of a wave. The wave bearing us has scarcely started its run; those who thought it was already slackening, spoke centuries too soon. We are poised now, in the precarious but exhilarating balance that is the essence of real living, the antithesis of mere existence. Behind us roars the reef we have already passed; beneath us the great wave, as yet barely flecked with foam, lumps its back still higher from the sea.

And ahead …

We cannot tell; we are too far out to see the unknown land. It is enough to ride the wave.

The whole of the above chapter was written at the beginning of 1960, almost ten years before the first Apollo landing; however, the argument and conclusions seem even more relevant today now that the first era of lunar exploration has ended.

I have developed these ideas in much greater detail in the Epilogue to the Apollo 11 astronauts' own book, *First on the Moon.*

NINE

YOU CAN’T GET THERE FROM HERE

There is a striking, though clumsy, phrase from the autobiography of the nineteenth-century writer Richard Jeffries that has stuck in my mind for many years: ‘The unattainable blue of the flower of the sky.’ *Unattainable*: that is a word we seldom use these days, now that men have walked on the surface of the Moon. Yet only a century ago the Poles were utterly unknown, much of Africa was still as mysterious as in the time of King Solomon, and no human being had descended a hundred feet into the sea or risen more than a mile into the air. We have gone ‘so far in so short a time, and will obviously go so much farther if our species survives its adolescence, that I would like to pose a question which would have seemed very odd to our ancestors. It is this: ‘Is there *any* place which will always remain inaccessible to us, whatever scientific advances the future may bring?’

One candidate springs to mind at once. Only 4,000 miles from where I am sitting there is a point far more difficult to reach than the other side of the Moon – or, for that matter, than the other side of Pluto. It is also 4,000 miles from you; as you have probably guessed, I refer to the centre of the Earth.

With all apologies to Jules Verne, one cannot reach this interesting spot by descending into the crater of Mount Sneffels. In fact, it is impossible to descend more than a couple of miles through any system of craters, caves or tunnels – natural or artificial. The deepest mine goes down only 7,000 feet.

Just as it does in the sea, the pressure below the Earth’s surface increases with depth, owing to the weight of the material above. The surface rocks of our planet are about three times as dense as water; therefore, as we go downwards into the Earth the pressure rises three times as quickly as in the sea. When the bathyscope *Trieste* reached the Challenger Deep, seven miles below the Pacific, there was a pressure of over a thousand tons on every square foot of its surface, and the walls of the observation sphere had to be made of steel five inches thick. The same pressure would be reached only two miles down inside the Earth, and this is a mere scratch on the surface of the globe. At the Earth’s centre, the pressure is estimated to be over 3,000,000 tons per square foot, or 3,000 times that which *Trieste* encountered.

Under such pressures, rocks and metals flow like liquids. In addition, the temperature rises steadily towards the interior, reaching perhaps 6,000° F at the centre. It is obvious, therefore, that we cannot hope to find a ready-made road into the heart of our planet, and the old idea of a ‘Hollow Earth’ (once put forward as a serious scientific theory) must be reluctantly dismissed – together with a whole host of subterranean fantasies, such as Edgar Rice Burroughs’ *At the Earth’s Core.*

The greatest depth to which the oil companies – the most energetic of underground explorers – have so far drilled is just over five miles. This is a quarter of the way through the solid crust of the Earth, which is about twenty miles thick beneath the continents; under the oceans, the crust is much thinner and it should soon be possible to drill through it to obtain samples of the unknown material upon which it floats.

The conventional drilling technique involves turning a bit at the end of thousands of feet of pipe, rotated by an engine at the surface. As the drill gets deeper, more and more energy is lost in friction against the hole, and it takes hours to lift and lower the miles of piping every time a drill has to be changed.

Newer methods do away with the rotating piping and put the power source on the drill itself, driving it electrically or by hydraulic pressure. The Russians, who have pioneered in this field, have also developed what is effectively a rocket-drill, which burns its way into the ground behind a 6,000° oxy-kerosene jet. Using one or other of these techniques, it would now be possible to drill a ten-mile shaft at the cost of several million dollars. This would take us halfway through the crust of the Earth – or a fourhundredth of the way to the centre.

A six-inch drill-hole is not what most people would have in mind when they speak of underground exploration, so let us look at some more exciting possibilities. Russian mining engineers have already built man-carrying mechanical moles for tunnelling at shallow depths; they are very similar to the device that Burrough’s hero employed to reach Pellucidar, the world inside the Earth. These machines solve the problem of soil-disposal in exactly the same way as does the common or garden mole, which was the prototype on which their design was based; the earth loosened by the drilling head is compacted and tamped to form the tunnel wall.

Even in fairly soft soil, the mechanical mole is very slow-moving. Its speed is limited to a mile or so a day by the power available (electricity is supplied through a trailing cable) and by the wear and tear on the drilling mechanism. An ‘earth probe’ that really hoped to get anywhere would have to have a fundamentally new type of excavating technique, and a very considerable supply of energy.

Nuclear reactions could provide the energy underground, as they already do undersea. As for the method of excavation, here again the Russians (who seem to be as interested in subterranean as in astronomical exploration) have suggested one answer. They are now using high-frequency electric currents to blast a way through rocks by sheer heat, and an underground arc could burn its way through the Earth just as fast as one could pour energy into it. Laser ultrasonic vibrations might also do the trick; they are now being employed on the small scale for cutting through materials too hard to be worked with ordinary tools.

A man-carrying, nuclear-powered ‘subterrene’ is a nice concept for any claustrophobe to meditate upon. For most purposes, there would be little point in putting a man in it; he would have to rely entirely upon the machine’s instruments, and his own senses could contribute nothing to the enterprise. All the scientific observations and collection of samples could be done automatically according to a prearranged programme. Moreover, with no human crew to sustain, the vehicle could take its time. It might spend weeks or months wandering round the roots of the Himalayas or under the bed of the Atlantic before it headed for home with its cargo of knowledge.

The depth that such an earth-probe could reach would be limited by the pressure its walls could sustain. This might be very high indeed, if it were designed as a solid body and the empty spaces inside it were filled with liquid to provide additional strength. (Another argument for having no crew.)

In the laboratory, steady pressures of a quarter of a million tons per square foot have now been produced; this is equivalent to the pressure four hundred miles inside the Earth. This does not mean that we can build vehicles theoretically capable of going four hundred miles down, but a tenth of this figure does not seem beyond the bounds of possibility. Temperature is a less serious problem; apart from occasional hot-spots like volcanoes, the temperatures in the crust do not exceed 600° or 700° F. It appears, therefore, that we may eventually explore most of the Earth’s crust, if we really wish to do so, with machines which can be visualized in terms of today’s engineering techniques.

Difficult though the problems of physically exploring the outer layers of the Earth may be, they are quite trivial compared with those we would have to face if we hope to travel into the mantle (the next 1,800 miles) or the core (from 1,800 miles down to the centre). No existing technology could help us here; all the materials and forces now available are hopelessly inadequate to deal with the combined effects of 6,000° F and three million *tons* to the square foot. We could not hold open a hollow space as large as a pinhead under such conditions for more than a fraction of a second; our toughest metals would not only flow like water, but would be converted into new and denser materials.

Any explorations of the Earth's deep interior cannot, therefore, be carried out by direct physical means, until and unless we gain control of forces several orders of magnitude more powerful than those that we possess today. But where we cannot travel, we may yet observe.

To see into the Earth with the precision and the definition with which we can explore the interior of our own bodies would be a marvellous achievement, of the greatest scientific and practical value. An X-ray photograph would have been unbelievable to an 1860 doctor; yet now we are building up what are virtually crude X-ray photos of the Earth, from the wave patterns produced by natural earthquakes or by explosions. (We can now make bangs big enough to shake our planet; it is not generally realized that the greatest explosion ever recorded – that of Karakotoa in 1883 – could be matched by a large fusion bomb.)*

The pictures are still very crude and lacking in fine detail; in particular, they tell us virtually nothing about the dense, central core, which is almost four thousand miles in diameter. We do not even know what it is composed of; the old theory that it is made of iron has been somewhat discredited lately, and it may well turn out to be some fairly conventional rock compressed by the enormous pressure into a form denser than lead.

What we want in order to explore this region are waves that will pass through the solid Earth as easily as X-rays pass through a human body, or lightwaves through the atmosphere, bringing back to us the information they gather on their journey. But such an idea is obviously absurd; you have only to think of the eight thousand miles of impenetrable rock and metal that screen you from the Antipodes …

Well, think again. There are, if not waves, *entities*, to which this massive Earth is as transparent as a soap-bubble. One is gravitation; though I have never met a physicist who would give me a straight answer to the question, 'Is gravity propagated in waves?' there is no doubt that it goes straight through the Earth as if it weren't there.

Something equally penetrating is that most peculiar and elusive of atomic particles, the neutrino. All other particles are stopped by a few inches, or at most a few feet, of materials such as lead. But the incredible neutrino, having no mass and no charge,* can shoot through a lead screen *fifty light-years thick* without being noticeably inconvenienced. Torrents of them are sweeping at the velocity of light through our so-called solid Earth at this very moment, and only one in a million million notices the trifling obstruction.

I am not suggesting that we could use either gravity or neutrino beams to give us close-ups of the Earth's core; both are probably too penetrating for the job, since you cannot scan an object with rays that go through it *completely*. But if such extraordinary entities exist in Nature, there may be others that possess the properties we need, and which we can use to map the interior of our planet as the radiologists map the inside of our bodies.

We may well discover, when such a survey is made, that there is nothing particularly interesting deep down inside the Earth – merely homogeneous shells of rock or metal, growing denser and denser towards the centre. Almost invariably, however, the universe turns out to be more complicated and surprising than we could have supposed; consider the way in which 'empty' space was found to be crowded with radio waves, cosmic dust, stray atoms, charged particles and heaven knows what, just as soon as we started to explore it. If Nature runs true to form, we will discover something deep inside the Earth that we will not be content merely to survey from a distance. We will want to get at it.

It may want to get at us, as I suggested some years ago in a short story called *The Fires Within.* This was based on the fact that forms of matter exist, under high pressure, so dense that by comparison ordinary rock would seem more tenuous than air. Indeed, this is a gross understatement; granite is about 2,000 times as dense as air, but the 'collapsed matter' in the heart of a dwarf star is 100,000 times, and in some cases 10,000,000 times, *as dense as granite.* Although even the pressures inside the Earth are far too small to crush atoms to this inconceivable density, I assumed, for purely fictional purposes, that creatures made of compressed matter might be swimming round inside the Earth as fish swim in the sea. I hope that no one takes the idea any more seriously than I did, but it may serve as a fable to prepare us for truths almost equally surprising, and much more subtle.

If our descendants – or their machines – ever succeed in sinking far down into the molten interior of the Earth, it may be through the use of techniques developed very far from home for quite different purposes. To consider these, let us take a detour far out into space – to the giant planet Jupiter, which our first automatic probes will be circling and surveying in the 1970s.

I am a little tired of reading in books about space-travel that Jupiter is a planet upon which men will 'certainly' never land – although I cannot pretend that I am very anxious to go there myself. Here is a world with eleven times the diameter of Earth, and more than a hundred times its area; if our entire planet was spread out across the face of Jupiter, it would appear about the size of India on the terrestrial globe. But we have never made any maps of Jupiter, for we have never seen its surface; like that of Venus, it is perpetually hidden by clouds – or what, for want of a better word, we may call clouds.

They are drawn out in ever-shifting parallel bands by the swift spin of the planet, and across half a billion miles of space we can watch the progress of mammoth storms or disturbances, many of them larger than Earth. The meteorology of Jupiter is a science whose very foundations are not yet laid; out there in the cold twilight so far from the Sun, a huge atmosphere of hydrogen and helium is being torn by unknown forces. Yet despite these convulsions, some features manage to survive for years at a time; the most famous of these is the Great Red Spot, an immense oval object some 25,000 miles long which has been observed, on and off, certainly for 120 years and perhaps for three centuries.

Because of Jupiter's size, and the scale of the events taking place there, it is natural to assume that its atmosphere is very much deeper than ours – perhaps a thousand, rather than a hundred, miles in thickness. But this is not the case; because Jupiter's gravity is more than 2½ times Earth's, the planet's atmosphere is compressed into a layer which may be only fifty miles deep.

At the bottom of that layer, the pressure must mount to values which we know only in the depths of our oceans. To enter the atmosphere of Jupiter we would need not merely a spaceship, but a bathyscope. There may be no definite solid surface on which any vehicle could land; the hydrogen may become steadily more dense until it turns first to a liquid slush, then – when the pressure reaches a thousand times that at the bottom of the Challenger Deep – to a metallic solid.

Yet some day, men are going to visit this world; the exploration of Jupiter may be one of the greatest enterprises of the twenty-first century. Jupiter will be the laboratory in which we will learn to withstand, control and use really high pressures, and from this work may arise vast new industries in the years to come. (There is no lack of raw materials on a world that weighs three hundred times as much as Earth.) When we have learned how to survive in the lower levels of the Jovian atmosphere, we will be better prepared to burrow into our own planet.*

On Jupiter our main problem will be pressure – and perhaps the sheer violence of gales that may blow at hundreds of miles an hour. We will not have to contend with high temperatures; the outer layers of the atmosphere are at about 250° *below* zero F, but at 'ground level' it may be slightly tropical, though that is now anyone's guess. If there are places in the Solar System that are unattainable because of temperature alone, we must look for them much closer to the Sun.

The planet Mercury is an obvious choice. This little world – just over 3,000 miles in diameter – has such a slow rotation period that the sun takes 88 of our days to cross the sky. As the solar radiation is also ten times more intense than on Earth, the temperature at the centre of the illuminated hemisphere must rise to 700° or 800° F. And on the dark side, where the only heat received is the feeble glow of starlight, it is at least four hundred degrees below zero.

These temperatures, extreme though they are by ordinary standards, are well inside the range of today's industrial and scientific techniques. The conquest of Mercury will not be an easy project, and not a few men and machines will perish in the attempt. But we will have to get closer – much closer – to the Sun before we run into real trouble.

The temperature rises quite slowly at first as we move in towards the central fire of the Sun; here are some figures which show what would happen to a spaceship whose hull was at a comfortable 65° F in the vicinity of Earth.

As the ship went past Venus, 67,000,000 miles from the Sun, the hull would reach 160° F; at the orbit of Mercury, 36,000,000 miles from the Sun, it would touch 400° F. We would have to approach the Sun to within 10,000,000 miles before the temperature passed 1,000°.

Five million miles out, it would be approaching 2,000°; 1,000,000 miles, 4,500° F. This last distance is only half a million miles above the surface of the Sun, which is at a temperature of about 9,000° F.

Materials are known which remain solid at temperatures above 6,000° F; graphite starts evaporating around 6,800° F; while hafnium carbide holds out to 7,500° F – the record, to the best of my knowledge. Thus we could send a hafnium carbide nose-cone to well within a million miles of the Sun – a hundredth of the Earth's distance – and hope to get it back in one piece. Instrument-carrying, expendable probes, well protected with layers of refractory material which slowly boiled away, could even reach the surface of the sun before they disintegrated.

But how close to the Sun could a *man-carrying* ship approach in safety? The answer to this question depends upon the skill and ingenuity of the refrigeration experts: my guess is that 5,000,000 miles is an attainable distance even with a crew-carrying vehicle.

There is one useful trick we may employ to get quite close to the Sun in (almost) perfect safety. This is to use a convenient asteroid or comet as a sunshade, and the best choice known at the moment is the little flying mountain appropriately named Icarus.

This minor planet travels on an orbit that every thirteen months brings it within a mere 17,000,000 miles of the Sun. Occasionally, it also passes quite close to Earth; it was within 4,000,000 miles of us in 1968.

Icarus is an irregular chunk of rock one or two miles in diameter, and at perihelion, beneath a sun that appears thirty times as big in the sky as it does from Earth, the surface of this little world 1,000° F. But it casts a cone, of shadow into space; and in the cold shelter of the shadow, a ship could ride safely around the Sun.

In a short story called *Summertime on Icarus*[*] I described how scientists might embark on such a somewhat hair-raising sleigh-ride to get themselves and their instruments close to the Sun, which would be unable to touch them as long as they remained on the cool side of their mile-thick shield of rock. Though it would be possible to construct artificial heat-shields, like today's re-entry nose-cones, it will be a long time before we can give ourselves the protection that Icarus would provide for nothing. Small though it is, this minor planet must weigh about 10,000,000,000 tons.

There may be other asteroids that go even closer to the Sun; if there are not, we may one day make them do so by a nudge at the right point in the orbit. And then, dug well in below the surface, scientists would be able to skim the atmosphere of the Sun, whipping across it and out again into space on a tight hair-pin bend.

It is interesting to work out how long the ride would take. Being a rather small star, the Sun is 'only' 3,000,000 miles in circumference. A satellite just outside its atmosphere would move at about 1,000,000 mph, so would circle it every three hours.

A comet or asteroid falling towards the Sun from the distance of Earth would be moving somewhat faster than this at its point of closest approach. It would flash across the surface of the Sun at 1,250,000 mph, and so would make its swing round the Sun in little more than an hour, before heading off into space again. Even if a few megatons of rock boiled away in the process, the instruments and observers deep inside the asteroid would be safe – unless, of course, there was a navigational error and they plunged too deeply into the solar atmosphere, to burn up through friction as so many artificial satellites of Earth have already done.

What a ride that would be! Imagine flashing high above the centre of a giant sunspot, a gaping crater 100,000 miles across, spanned by bridges of fire over which our planet Earth could roll like a child's hoop along the pavement. The explosion of the most powerful hydrogen bomb would pass unnoticed in that inferno, where whole continents of incandescent gas leap skyward at hundreds of miles a second, sometimes escaping completely into space.

Ray Bradbury, in his short story, *The Golden Apples of the Sun,* once described the descent of a spaceship into the solar atmosphere to obtain a sample of the Sun (which we now know, incidentally, to be 90 per cent hydrogen, 10 per cent helium, plus a mere trace of all the other elements). When I first read this story, I dismissed it as charming fantasy; now I am not so sure. In one sense we have already reached out and touched the Sun, for we made radar contact with it in 1959 – and how unbelievable *that* would have seemed a generation ago! Even a close physical approach no longer seems completely out of the question, thanks to the development of the new science of plasma physics, born since 1950.

Plasma physics, sometimes known by the jaw-breaking name of magneto-hydrodynamics, is concerned with the handling of very hot gases in magnetic fields. Already it has enabled us to produce temperatures of tens of millions of degrees in the laboratory, and ultimately it may lead to the goal of limitless power from hydrogen fusion. I suggest that, when we have acquired some real mastery of this infant science, it will also give us magnetic or electric shields that can provide far more effective protection against both temperature *and* pressure than can be obtained from any walls of metal. The old science-fiction idea of the impenetrable shield of force may no longer be a dream; we may be forced to discover it, as the only real answer to the ICBM. When we possess it, we may have a key not only to the interior of the Earth, but even, perhaps, to the interior of the Sun.

This search for the unattainable has taken us, in imagination, to some strange and hostile places. The centre of the Earth, the depths of the Jovian atmosphere, the surface of the Sun – though these are certainly beyond the reach of today's technologies, I have given reasons for thinking that they need not be for ever out of bounds, if we really desire to visit them. But we have far from exhausted the Universe's capacity for ingenious surprises; and if you are still with me, we have one more call to make.

I have already mentioned dwarf stars, which are tiny suns in the last stages of stellar evolution. Some of them are smaller than Earth, yet they contain packed within their few thousand miles of radius as much matter as goes to make up a normal star. The very atoms of which they are composed are crushed beneath the enormous pressures in their interiors, to densities which may rise to many millions of times that of water. A cubic inch of matter from such a star may weigh more than a hundred tons.

Though most dwarfs are red or white-hot, cool 'Black Dwarfs' are a theoretical possibility. They would be the very end of the evolutionary line, and would be extremely difficult to detect because, like planets, they would radiate no light of their own but could be observed only by reflection, or when they eclipsed some other body. Since our galaxy is still quite young – not much more than 25,000,000,000 years old – it is probable that none of its stars has yet reached the final Black Dwarf stage; but their time will come.

These stellar corpses will be among the most fascinating (and sinister) objects in the universe. Their combination of great mass and tiny size would give them enormous gravitational fields – up to a million times as powerful as Earth's. A world with such a gravity would have to be perfectly spherical; no hills or mountains could rear themselves more than a fraction of an inch above its surface, and its atmosphere would be only a few feet in depth.

At a million gravities, all objects – even if made of the strongest metal – would flow under their own weight until they had flattened themselves into a thin film. A man would weigh as much as the *Queen Elizabeth* and would collapse so quickly that his disintegration could not be followed by the naked eye, for it would take less than a thousandth of a second. A fall through a distance of *a third of an inch* would be equivalent to falling, on Earth, from the top of Mount Everest to sea level.

Yet despite the enormous gravitational field, it would be possible to approach within a few hundred feet of such a body. A spaceship or a space-probe aimed into a sufficiently precise orbit could, in theory at least, swing past it like a comet whipping round the Sun. If you were in such a ship you would feel nothing, even at the moment of closest approach. At an acceleration of a million gravities, you would still be completely weightless, for you would be in free-fall. The ship would reach a maximum speed of some 25,000,000 mph as it raced low over the surface of the dying star; then it would recede into space once more, escaping beyond its reach.

But what of an actual *landing* on a Dwarf? Well, such a feat is conceivable if we make two assumptions, neither of which violates any known physical laws. We would need propulsion systems several million times more powerful than any known today, and we would require an absolutely complete and reliable means of neutralizing gravity, so that the crushing external field could be cancelled to six decimal places. If even 0.001 per cent of that frightful gravity 'leaked' into the ship, its occupants would be pulped. They would never feel anything, of course, if the compensating field failed; it would all be over so quickly that the nerve fibres would have no time to react.

The world of a Black Dwarf would be weird almost beyond imagination; the very geometry of space would be affected by the gravitational field, and light itself would no longer travel in perfectly straight lines, but would suffer appreciable bending. What other distortions of the natural order of things may take place in such a world we cannot guess today; which is one reason why we will go there if it ever proves possible.

In our own time, men have peered through the portholes of a bathyscope into a region, only inches away, where they would be crushed in a fraction of a second by a pressure of a thousand tons on every square foot of their bodies. That was a wonderful achievement – a triumph of courage and engineering skill. Centuries in the future, and light-years from Earth, there may be men peering out of portholes into the still more feeble gravity, you are more than a thousand miles tall.

And how strange it will be, to look down upon the smooth, geometrically perfect surface on the other side of the ship's compensating field – and to realize that, in terms of Earth's feeble gravity, you are more than a thousand miles tall.

Postscript – Neutron Stars

Since this chapter was written, the radio astronomers have discovered 'pulsars', which are believed to be neutron stars – objects about ten miles across with a density a *hundred million times* that of the already incredible White Dwarfs. The gravity at the surface of such an object would be a hundred billion (100,000,000,000) times that of Earth – or a hundred thousand times that of a White Dwarf!

Despite Clarke's First Law, my imagination quails at the thought of landing on such an object. Even a free-orbit approach within several radii (a few dozen miles!) would be excessively dangerous, because of the enormous tidal forces involved (see 'Neutron Tide' in *The Wind from the Sun).*

TEN

SPACE, THE UNCONQUERABLE

Man will never conquer Space. After all that has been said in the last two chapters, this statement sounds ludicrous. Yet it expresses a truth which our forefathers knew, which we have forgotten – and which our descendants must learn again, in heartbreak and loneliness.

Our age is in many ways unique, full of events and phenomena which never occurred before and can never happen again. They distort our thinking, making us believe that what is true now will be true for ever, though perhaps on a larger scale. Because we have annihilated distance on this planet, we imagine that we can do it once again. The facts are far otherwise, and we will see them more clearly if we forget the present and turn our minds towards the past.

To our ancestors, the vastness of the Earth was a dominant fact controlling their thoughts and lives. In all earlier ages than ours, the world was wide indeed and no man could ever see more than a tiny fraction of its immensity. A few hundred miles – a thousand, at the most – was infinity. Great empires and cultures could flourish on the same continent, knowing nothing of each other's existence save fables and rumours faint as from a distant planet. When the pioneers and adventurers of the past left their homes in search of new lands, they said goodbye for ever to the places of their birth and the companions of their youth. Only a lifetime ago, parents waved farewell to their emigrating children in the virtual certainty that they would never meet again.

And now, within one incredible generation, all this has changed. Over the seas where Odysseus wandered for a decade, the tourist-laden jets whisper their way within the hour. And above that, the closer satellites span the distance between Troy and Ithaca in less than a minute.

Psychologically as well as physically, there are no longer any remote places on earth. When a friend leaves for what was once a far country, even if he has no intention of returning, we cannot feel that same sense of irrevocable separation that saddened our forefathers. We know that he is only hours away by jet-liner, and that we have merely to reach for the telephone to hear his voice. And in a very few years, when the satellite communication network is perfected, we will be able to see friends on the far side of the earth as easily as we talk to them on the other side of the town. Then the world will shrink no more, for it will have become a dimensionless point.

But the new stage that is opening up for the human drama will never shrink as the old one has done. We have abolished space here on the little Earth; we can never abolish the Space that yawns between the stars. Once again, as in the days when Homer sang, we are face to face with immensity and must accept its grandeur and terror, its inspiring possibilities and its dreadful restraints. From a world that has become too small, we are moving out into one that will be for ever too large, whose frontiers will recede from us always more swiftly than we can reach out towards them.

Consider first the fairly modest solar, or planetary, distances which we are now preparing to assault. The very first Lunik made a substantial impression upon them, travelling more than 200,000,000 miles from Earth – six times the distance to Mars. When we have harnessed nuclear energy for space-flight, the Solar System will contract until it is little larger than the Earth today. The remotest of the planets will be perhaps no more than a week's travel from Earth, while Mars and Venus will be only a few hours away.

This achievement, which will be witnessed within a century, might appear to make even the Solar System a comfortable, homely place, with such giant planets as Saturn and Jupiter playing much the same role in our thoughts as do Africa or Asia today. (Their qualitative differences of climate, atmosphere and gravity, fundamental though they are, do not concern us at the moment.) To some extent this may be true, yet as soon as we pass beyond the orbit of the Moon, a mere quarter-million miles away, we will meet the first of the barriers that will sunder Earth from her scattered children.

The marvellous telephone and television network that will soon enmesh the whole world, making all men neighbours, cannot be extended into space. *It will never be possible to converse with anyone on another planet.*

Do not misunderstand this statement. Even with today's radio equipment, the problem of sending speech to the other planets is almost trivial. But the messages will take minutes – sometimes hours – on their journey, because radio and light waves travel at the same limited speed of 186,000 miles a second. Twenty years from now you will be able to listen to a friend on Mars, but the words you hear will have left his mouth at least three minutes earlier, and your reply will take a corresponding time to reach him. In such circumstances, an exchange of verbal messages is possible – but *not* a conversation. Even in the case of the nearby Moon, the two-and-a-half second time-lag will be annoying. At distances of more than 1,000,000 miles, it will be intolerable.

To a culture which has come to take instantaneous communication for granted, as part of the very structure of civilized life, this ‘time barrier’ may have a profound psychological impact. It will be a perpetual reminder of universal laws and limitations against which not all our technology can ever prevail. For it seems as certain as anything can be that no signal – still less any material object – can ever travel faster than light.

The velocity of light is the ultimate speed limit, being part of the very structure of space and time. Within the narrow confines of the Solar System, it will not handicap us too severely, once we have accepted the delays in communication which it involves. At the worst, these will amount to ten hours – the time it takes a radio signal to span the orbit of Pluto, the outer-most planet. Between the three inner worlds, Earth, Mars and Venus, it will never be more than twenty minutes —not enough to interfere seriously with commerce or administration, but more than sufficient to shatter those personal links of sound or vision that can give us a sense of direct contact with friends on Earth, wherever they may be.

It is when we move out beyond the confines of the Solar System that we come face to face with an altogether new order of cosmic reality. Even today, many otherwise educated men – like those savages who can count to three but lump together all numbers beyond four – cannot grasp the profound distinction between *solar* and *stellar* space. The first is the space enclosing our neighbouring worlds, the planets; the second is that which embraces those distant suns, the stars. *And it is literally millions of times greater.*

There is no such abrupt change of scale in terrestrial affairs. To obtain a mental picture of the distance to the nearest star, as compared with the distance to the nearest planet, you must imagine a world in which the closest object to you is only five feet away – and then there is nothing else to see until you have travelled 1,000 miles.

Many conservative scientists, appalled by these cosmic gulfs, have denied that they can ever be crossed. Some people never learn; those who not long ago laughed at the idea of travel to the planets are now quite sure that the stars will always be beyond our reach. And again they are wrong, for they have failed to grasp the great lesson of our age – that if something is possible in theory, and no fundamental scientific laws oppose its realization, then sooner or later it will be achieved, granted a sufficiently purposeful incentive.

One day – it may be in this century, or it may be a thousand years from now – we shall discover a really efficient means of propelling our space-vehicles. Every technical device is always developed to its limit (unless it is superseded by something better), and the ultimate speed for spaceships is the velocity of light. They will never reach that goal, but they will get very close to it. And then the nearest star will be less than five years' voyaging from Earth.

Our exploring ships will spread outwards from their home over an ever-expanding sphere of space. It is a sphere which will grow at almost – but never quite – the speed of light. Five years to the triple system of Alpha Centauri, ten to that strangely matched doublet Sirius A and B, eleven to the tantalizing enigma of 61 Cygni, the first star suspected of possessing a planet. These journeys are long, but they are not impossible. Man has always accepted whatever price was necessary for his explorations and discoveries, and the price of Space is Time.

Even voyages which may last for centuries or millennia will one day be attempted. Suspended animation, an undoubted possibility, may be the key to interstellar travel. Self-contained cosmic Arks which will be tiny travelling worlds in their own right may be another solution, for they would make possible journeys of unlimited extent, lasting generation after generation. The famous Time Dilation effect predicted by the Theory of Relativity, whereby time appears to pass more slowly for a traveller moving at almost the speed of light, may be yet a third. And there are others.

With so many theoretical possibilities for interstellar flight, we can be sure that at least one will be realized in practice. Remember the history of the atomic bomb; there were three different ways in which it could be made, and no one knew which was best. So they were all tried – and they all worked.

Looking far into the future, therefore, we must picture a slow (little more than half a billion miles an hour!) expansion of human activities outwards from the Solar System, among the suns scattered across the region of the galaxy in which we now find ourselves. These suns are on the average five light-years apart; in other words, we can never get from one to the next in less than five years.

To bring home what this means, let us use a down-to-earth analogy. Imagine a vast ocean, sprinkled with islands – some desert, others perhaps inhabited. On one of these islands an energetic race has just discovered the art of building ships. It is preparing to explore the ocean, but must face the fact that the very nearest island is five years' voyaging away, and that no possible improvement in the technique of ship-building will ever reduce this time.

In these circumstances (which are those in which we will soon find ourselves) what could the islanders achieve? After a few centuries, they might have established colonies on many of the nearby islands, and have briefly explored many others. The daughter colonies might themselves have sent out further pioneers, and so a kind of chain-reaction would spread the original culture over a steadily expanding area of the ocean.

But now consider the effects of the inevitable, unavoidable time-lag. There could be only the most tenuous contact between the home island and its offspring. Returning messengers could report what had happened on the nearest colony – five years ago. They could never bring information more up to date than that, and dispatches from the more distant parts of the ocean would be from still further in the past – perhaps centuries behind the times. There would never be News from the other islands, but only History.

No oceanic Alexander or Caesar could ever establish an empire beyond his own coral reef; he would be dead before his orders reached his governors. Any form of control or administration over other islands would be utterly impossible, and all parallels from our own history thus cease to have any meaning. It is for this reason that the popular science-fiction stories of interstellar empires and intrigues become pure fantasies, with no basis in reality. Try to imagine how the War of Independence would have gone, if news of Bunker Hill did not arrive in England until Disraeli was Victoria's Prime Minister, and his urgent instructions to deal with the situation reached America during President Eisenhower's second term. Stated in this way, the whole concept of interstellar administration or culture is seen to be an absurdity.

All the star-borne colonies of the future will be independent, whether they wish it or not. Their liberty will be inviolably protected by Time as well as Space. They must go their own way and achieve their own destiny, with no help or hindrance from Mother Earth.

At this point, we will move the discussion on to a new level and deal with an obvious objection. Can we be *sure* that the velocity of light is indeed a limiting factor? So many 'impassable' barriers have been shattered in the past; perhaps this one may go the way of all the others.

We will not argue the point, or give the reasons why scientists believe that light can never be outraced by any form of radiation or any material object. Instead, let us assume the contrary and see just where it gets us. We will even take the most optimistic possible case, and imagine that the speed of transportation may eventually become infinite.

Picture a time when, by the development of techniques as far beyond our present engineering as a transistor is beyond a stone axe, we can reach anywhere we please *instantaneously,* with no more effort than by dialling a number. This would indeed cut the Universe down to size, and reduce its physical immensity to nothingness. What would be left?

Everything that really matters. For the Universe has two aspects – its scale, and its overwhelming, mind-numbing complexity. Having abolished the first, we are now face-to-face with the second.

What we must now try to visualize is not size, but quantity. Most people today are familiar with the simple notation which scientists use to describe large numbers; it consists merely of counting zeroes, so that a hundred becomes 10^2, a million, 10^6; a billion, 10^9 and so on. This useful trick enables us to work with quantities of any magnitude, and even defence budget totals look modest when expressed as $5.76 X 10^9 in stead of $5,760,000,000.

The number of other suns in our own galaxy (that is, the whirlpool of stars and cosmic dust of which our Sun is an out-of-town member, lying in one of the remoter spiral arms) is estimated at about 10^{11} – or written in full, 100,000,000,000. Our present telescopes can observe something like 10^9 other galaxies, and they show no sign of thinning out even at the extreme limit of vision. There are probably at least as many galaxies in the whole of creation as there are stars in our own galaxy, but let us confine ourselves to those we can see. They must contain a total of about 10^{11} times 10^9 stars, or 10^{20} stars altogether.

1 followed by 20 other digits is, of course, a number beyond understanding. There is no hope of ever coming to grips with it, but there are ways of hinting at its implications.

Just now we assumed that the time might come when we could dial ourselves, by some miracle of matter-transmission, effortlessly and instantly round the Cosmos, as today we call a number in our local exchange. What would the Cosmic Telephone Directory look like, if its contents were restricted to suns and it made no effort to list individual planets, still less the millions of places on each planet?

The directories for such cities as London and New York are already getting somewhat out of hand, but they list only about a million – 10^6 – numbers. The Cosmic Directory would be 10^{14} times bigger, to hold its 10^{20} numbers. It would contain more pages than all the books *that have ever been produced since the invention of the printing press.*

To continue our fantasy a little further, here is another consequence of 20-digit telephone numbers. Think of the possibilities of cosmic chaos, if dialling 27945015423811986385 instead of 27945015243811986385 could put you at the wrong end of Creation … This is no trifling example; look well and carefully at these arrays of digits, savouring their weight and meaning, remembering that we may need every one of them to count the total tally of the stars, and even more to number their planets.

Before such numbers, even spirits brave enough to face the challenge of the light-years must quail. The detailed examination of all the grains of sand on all the beaches of the world is a far smaller task than the exploration of the universe.

And so we return to our opening statement. Space can be mapped and crossed and occupied without definable limits; but it can never be conquered. When our race has reached its ultimate achievement, and the stars themselves are scattered no more widely than the seed of Adam, even then we shall still be like ants crawling on the face of the earth. The ants have covered the world, but have they conquered it – for what do their countless colonies know of it, or of each other?

So it will be with us as we spread outwards from Mother Earth, loosening the bonds of kinship and understanding, hearing faint and belated rumours at second – or third – or thousandth-hand of an ever-dwindling fraction of the entire human race. Though Earth will try to keep in touch with her children, in the end all the efforts of her archivists and historians will be defeated by time and distance, and the sheer bulk of material. For the number of distinct societies or nations, when our race is twice its present age, may be far greater than the total number of all the men who have ever lived up to the present time.

We have left the realm of comprehension in our vain effort to grasp the scale of the universe; so it must always be, sooner rather than later.

When you are next out of doors on a summer night, turn your head towards the zenith. Almost vertically above you will be shining the brightest star of the northern skies – Vega of the Lyre, twenty-six years away at the speed of light, near enough the point-of-no-return for us short-lived creatures. Past this blue-white beacon, fifty times as brilliant as our sun, we may send our minds and bodies, but never our hearts.

For no man will ever turn homewards from beyond Vega, to greet again those he knew and loved on Earth.

ELEVEN

ABOUT TIME

Man is the only animal to be troubled by Time, and from that concern comes much of his finest art, a great deal of his religion, and almost all his science. For it was the temporal regularity of nature – the rising of sun and stars, the slower rhythm of the seasons – which led to the concept of law and order and in turn to astronomy, the first of all sciences. Changeless environments like the deep ocean or the cloud-wrapped surface of Venus provide no stimulus to intelligence and in such places it may never be able to arise.

It is not surprising, therefore, that human cultures which exist in regions of negligible climatic variation, like Polynesia and tropical Africa, are primitive and have little conception of Time. Other cultures, forced by their surroundings to be aware of Time, have become obsessed by it. Perhaps the classic example is that of Ancient Egypt, where life was regulated by the annual flooding of the Nile. No other civilisation, before or since, has made such determined efforts to challenge eternity, and even to deny the existence of death.

Time has been a basic element in all religions, where it has been combined with such ideas as reincarnation, foretelling the future, resurrection and the worshipping of the heavenly bodies – as shown by the monolithic calendar of Stonehenge, the Zodiac from the Dendera Temple and the ecclesiastical architecture of the Mayas. Some faiths (Christianity, for instance) have placed Creation and the beginning of Time at very recent dates in the past, and have anticipated the end of the Universe in the near future. Other religions, such as Hinduism, have looked back through enormous vistas of Time and forward to even greater ones. It was with reluctance that Western astronomers realized that the East was right, and that the age of the Universe is to be measured in billions rather than millions of years – if it can be measured at all.

And it is only in the last fifty years that we have learned something about the true nature of Time, and have even been able to influence its progress – though as yet, by no more than millionths of a second. Ours is the first generation, since balance wheels and pendulums started oscillating, to realize that Time is neither absolute nor inexorable, and that the tyranny of the clock may not last for ever.

It is hard not to think of Time as an adversary, and in a sense, all the achievements of human civilization are the trophies that Man has won in his war against Time. Whatever their motives may have been, the cave artists of Lascaux were the first to win any gains for mankind. About a thousand generations ago, when the mammoth and the sabre-toothed tiger still walked the Earth, they discovered a way of sending not merely their bones but some at least of their thoughts and feelings into the future. We can look through their eyes, across the gulfs of time, and see the animals that shared their world. But we can see little more than that.

The invention of poetry, perhaps as part of religious rituals, was the next advance. Ordinary words and phrases are fleeting, forgotten as soon as uttered. However, once they are arranged in a pattern, something magical happens. As Shakespeare (most Time-obsessed of writers) truly remarked:

Not marble, nor the gilded monuments
Of princes, shall outlive this powerful rhyme.

Bards and minstrels like Homer carried in their heads the only record of prehistory we possess, though until the invention of writing it was always liable to distortion or total loss.

Writing – perhaps the most important single invention that mankind ever made or ever will make – changed all that. Plato and Caesar speak to us across the ages more clearly than most of our fellow-men. And with the invention of the printing-press, the written word became virtually immortal. Manuscripts and scrolls and papyri are vulnerable and easily destroyed, but since the time of Gutenberg, very few works of permanent value can have vanished into oblivion.

Little more than a century ago, writing and the visual arts were reinforced by the wonderful recording device of the camera. Photography is such a commonplace that we have long forgotten how marvellous it really is; if it were as difficult and expensive to take a photograph as, say, to launch a satellite, we would then give the camera the credit that is due to it.

No other artifact created by the brain or the hand is as evocative as a photograph. It alone can take us back into the past, can make us feel – in joy or sadness – '*This* is how it really was, in such a place and at such a time'. A cheap box camera can provide for anyone of us what the greatest sculptors of the ancient world laboured for years to give the Emperor Hadrian – the exact image of a lost love. With the invention of photography, some aspects of the past became for the first time directly accessible, with the minimum of selective intervention and distortion by a human mind. Not the least important respect in which the American Civil War differed from all previous conflicts was the presence of Matthew Brady.

The camera – and especially the movie camera, when it arrived some fifty years later – gave us the power not merely to recapture time but to dissect and distort it. Sights too swift or too slow for the human eye to follow were suddenly made visible by high-speed and time-lapse photography. Anyone who has watched the vicious battle to the death between two vines, tearing at each other with hour-long slashes of their tendrils, can never again feel the same way about the vegetable kingdom. The movements of clouds, the splash of a raindrop, the passage of the seasons, the beat of a hummingbird's wings – before our century men could only guess at these things, or glimpse them merely as independent, unrelated snapshots. Now they can watch them with their own eyes and see them as an organic, connected whole.

When the phonograph broke upon the world in 1877, Time lost its absolute control over sound as well as sight. Like the camera, the phonograph was totally unexpected, though the ingenious Cyrano de Bergerac had mentioned 'talking books' in one of his scientific romances. However, unlike the camera and most other modern inventions, the phonograph stands in a class by itself because of its extreme simplicity. It does not detract from Edison's achievement to say that, given the necessary instructions, any competent Greek artificer could have built an instrument that could have captured the voices of Socrates or Demosthenes for us. In the Athens Museum there are the remains of an astronomical computer far more complex than an acoustic phonograph, and sometimes I wonder …

Impressive though the achievements of the last hundred years have been, they are pitiful when we consider what we would *like* to do about Time if we had the power. Philosophers, scientists and poets have racked their brains over with the problem of Time; a man who combined all three roles expressed an universal regret when he lamented, almost a thousand years ago: 'The moving finger writes, and having writ, Moves on …' All our 'piety and wit' are powerless to alter the past, or even to change the rate at which we are swept into the future. Yet this may not always be the case.

If we make a list of the powers that we would like to have over Time, irrespective of their feasibility, it might run as follows:

Seeing the past
Reconstructing the past
Changing the past
Travelling into the past
Accelerating or retarding the present

Travelling into the future
Seeing the future

I can think of no possibilities (or for that matter impossibilities) not covered by one of these headings; let us see what we may hope to do about each of them.

As far as the first is concerned, it is worth remembering that we never see or experience anything *but* the past. The sounds you are hearing now come from a thousandth of a second back in time for every foot they have had to travel to reach your ears. This is best demonstrated during a thunderstorm, when the peal from a flash twelve miles away will not be heard for a full minute. If you ever see a flash and hear the thunder simultaneously, you will be lucky to be alive. I have done it once and do not recommend the experience.

What is true of sound is also true of light, though on a scale almost exactly a million times shorter. The peal of thunder from a lightning flash twelve miles away may take a minute to reach you, but your eyes know about it in less than a ten-thousandth of a second. For all ordinary terrestrial purposes, therefore, the speed of light is infinite. It is only when we look out into space that we see events that occurred centuries, or even millions of years, ago.

This is a very limited kind of penetration into the past; in particular, it offers no possibility of seeing into our *own* past. Nor can we hope that, when we have reached the worlds of nearby suns, we will find advanced races who have been watching us and recording our own lost history through super-telescopes – an idea that has been suggested by some naïve science-fiction authors. The light-waves from any events on the Earth's surface are badly scrambled on their way out through the atmosphere – even when clouds allow them to escape at all. And after that, they are so swiftly weakened by distance that no telescope could be built, even in theory, that would allow one to observe terrestrial objects smaller than several miles across from the distance of Mars. No creatures in a stellar system 900 light-years away are now watching the Battle of Hastings. The rays that started in 1066 are, by now, too feeble even to show an image of the whole Earth.

For there is a limit to the amplification of light, set by the nature of the light-waves themselves, and no scientific advances can circumvent it. In much the same way, we cannot hope to recapture vanished sounds, once they have dwindled below the general level of background noise. It has sometimes been said that no sound ever dies, but merely becomes too faint to be heard. This is not true; the vibrations from any sound are so swiftly damped out that, within a few seconds, they cease to exist in any physical sense. No amplifier can recapture the words you spoke a minute ago; even if it had infinite sensitivity, it would merely reproduce the random hiss of the air molecules as they collide with one another.

If there is any way in which we can ever observe the past, it must depend upon technologies not only unborn but today unimagined. Yet the idea does not involve any logical contradictions or scientific absurdities and in view of what has already happened in archaeological research, only a very foolish man would claim that it is impossible. For we have now recovered knowledge from the past which it seemed obvious must have been lost for ever, beyond all hope of recovery. How could we possibly expect to measure the rainfall in the year AD 784? That can be done by examining the thickness of tree-rings. How can we find the age of a piece of bone of unknown origin? Carbon 14 dating can do just this. Which way did the compass needle point, 20,000 years ago? The orientation of magnetic particles in ancient clays will tell us. How has the temperature of the oceans varied during the last half million years? We now have – and this is perhaps the most amazing achievement of all – a ‘time thermometer’ which actually follows the coming and going of the Ice Ages, so that we can say with some confidence that 210,000 years ago the average temperature of the sea was 84° F, whereas 30,000 years later it had dropped to 70°. You are hardly likely to guess how this has, been discovered; the trick is in knowing that the chalky shells of certain marine animals have a composition depending upon the temperature of the water in which they were formed, so that this can be deduced from a delicate and sophisticated analysis. Thus Professor Urey was able to tell that a fossil mollusc that lived in the seas covering Scotland 150,000,000 years ago was born in the summer, when the water temperature was 70° F, lived four years, and died in the spring.

Not long ago, such knowledge of the past would have seemed clairvoyance, not science. It has been achieved through the development of sensitive measuring instruments (byproducts, usually, of atomic research) which can detect the incredibly faint traces left upon objects by their past history. No one can yet say how far such techniques may be extended. There may be a sense in which all events leave some mark upon the universe, at a level not yet reached by our instruments. (But possibly, under very abnormal circumstances, by our senses: is this the explanation of ghosts?) The time may come when we can read such marks, now as invisible to us as the plain signs of a trail to an Indian scout or an aborigine tracker. And then, the curtain will lift from the Past.

At first sight, the ability to look back into Time would seem the most wonderful power that could be given to men. All lost knowledge would be recovered, all mysteries explained, all crimes solved, all hidden treasure found.

History would no longer be a patchwork of surmises and conjectures; where today we guess, we would *know*. And perhaps we might even reach the stage so poetically described by Wells in his short story *The Grisly Folk.*

> ‘A day may come when these recovered memories may grow as vivid as if we in our own persons had been there and shared the thrill and fear of those primordial days; a day may come when the great beasts of the past will leap to life again in our imaginations, when we shall walk again in vanished scenes, stretch painted limbs we thought were dust, and feel again the sunshine of a million years ago.’

With such powers we would indeed be like gods, able to roam at will down the ages. But only gods, surely, are fit to possess such powers. If the past were suddenly opened up to our inspection, we would be overwhelmed not only by the sheer mass of material, but by the brutality, horror and tragedy of the centuries that lie behind us. It is one thing to read about massacres, battles, plagues, Inquisitions, or to see them enacted in the movies. But what man could bear to look upon the immutable evil of the past, knowing that what he saw was real and beyond all remedy? Better, indeed, that the good and the bad lie for ever beyond such detailed scrutiny.

And there is another aspect of the matter. How would *we* care for the idea that, at some unknown time in the future, men not unlike ourselves except for their superior science may be peering into our lives, watching all our follies and vices as well as our rarer virtues? The next moment that you are engaged in some discreditable action, pause to contemplate the thought that you may be a specimen before a class in primitive psychology, a thousand years from now. A still worse possibility is that the *voyeurs* of some decadent future age may use their perverted science to spy upon our lives. Yet perhaps even that is better than the prospect that we may be too simple and archaic to interest them at all …

The reconstruction of the past is an idea even more fantastic than its observation; it includes that, and goes far beyond it. Indeed, it is nothing less than the concept of resurrection, looked at in a scientific rather than a religious sense.

Suppose that sometime in the future men acquire the power to observe the past in such detail that they can record the movement of every atom that ever existed. Suppose that they then reconstruct, on the basis of this information, selected people, animals and places from the past. Thus though you actually died in the twentieth century, another ‘you’, complete with all memories up to the moment of observation, might suddenly find himself in the far future, continuing to live a new existence from then onwards.

The fact that this is about as wild a fantasy as the mind of man can conceive does not mean that it should be dismissed as ridiculous. The suggestion has been put forward – by a French philosopher, I believe, – that by some such means the people of the future might attempt to redress the evils of the past. It would, of course, do nothing of the sort. Even if some super-science did recreate the victims of long-forgotten injustices and crimes, allowing them to continue their lives in happier circumstances, that would not change the sufferings of the originals in the least.

To do that – to *alter* the past, and make the moving finger erase its inscription – is a fit subject for fantasy, but not for science. To change the past involves so many paradoxes and contradictions that we are, surely, justified in regarding it as impossible. The classic argument against time-travel is that it would allow a man to go back into the past and to kill one of his direct ancestors, thus making himself – and probably a considerable fraction of the human race – non-existent.

Some ingenious writers (notably Robert Heinlein and Fritz Leiber) have accepted this challenge and said, in effect: ‘Very well – suppose such paradoxes *do* occur. What then?’ One of their answers is the concept of parallel time-tracks. They assume that the past is not immutable – that one could, for instance, go back to 1865 and deflect the aim of John Wilkes Booth in Ford’s Theatre. But by so doing, one would abolish our world and create another, whose history would diverge so much from ours that it would eventually become wholly different.

Perhaps in a sense all possible universes have an existence, like the tracks in an infinite marshalling yard, but we merely move along one set of rails at a time. If we could travel backwards, and change some key event in the past, all that we would really be doing would be going back to a switch-point and setting off on another time-track.

But it may not be as simple, if you will pardon the expression, as this. Other writers have developed the theme that, even if we could change individual events in the past, the inertia of history is so enormous that it would make no difference. Thus you might save Lincoln from Booth’s bullet – only to have another Confederate sympathizer waiting with a bomb in the foyer. And so on …

The most convincing argument against time-travel is the remarkable scarcity of time-travellers. However unpleasant our age may appear to the future, surely one would expect scholars and students to visit us, if such a thing were possible at all. Though they might try to disguise themselves, accidents would be bound to happen – just as they would if we went back to Imperial Rome with cameras and tape-recorders concealed under our nylon togas. Time-travelling could never be kept secret for very long; over and over again down the ages, chronic argonauts (to use the original and singularly uninspiring title of Wells' *The Time Machine)* would get into trouble and inadvertently disclose themselves. As it is, the chief evidence of a security leak from the future appears to be the notebooks of Leonardo da Vinci. Their parade of inventions from the succeeding centuries is astonishing, but hardly conclusive proof that fifteenth-century Italy had visitors from elsewhere.

Some science-fiction writers have tried to get round this difficulty by suggesting that Time is a spiral; though we may not be able to move along it, we can perhaps hop from coil to coil, visiting points so many millions of years apart that there is no danger of embarrassing collisions between cultures. Big game hunters from the future may have wiped out the dinosaurs, but the age of *Homo Sapiens* may lie in a blind region which they cannot reach.

You will gather from this that I do not take time-travel very seriously; nor, I think, does anyone else – even the writers who have devoted most effort and ingenuity to it. Yet the theme is one of the most fascinating – and sometimes the most moving – in the whole of literature, inspiring works as varied as *Jurgen* and *Berkeley Square.* It appeals to the deepest of all instincts in mankind, and for that reason it will never die.

A much less far-fetched and more realistic idea than travel into the past is that we might be able to vary the rate at which we move – or appear to move – into the future. To some extent, drugs already do this. For an anaesthetized man, time passes at an infinite rate. He closes his eyes for a second – and opens them perhaps hours later. Stimulants can have a slight effect in the other direction, and there have been many reports of the mental acceleration, real or imagined, produced by mescalin, hashish and other narcotics. Even if there were no undesirable side-effects, such a distortion of the time sense could only be very limited. No matter how fast a man's mind operated, the sheer inertia of his body would prevent him from moving his limbs at much more than their normal speed. If you put a super-fuel in the petrol tank of your car, the engine will tear itself to pieces – and the body of a man is an infinitely more delicately balanced organism than an automobile engine. We may be able to slow it down to an almost unlimited extent, making possible the old dream of suspended animation and a one-way trip into the future like that experienced by Rip Van Winkle. But we cannot accelerate it by means of drugs, so that a man could run a one-minute mile or do a day's work in an hour.

Yet perhaps this could be achieved in some other way, if we draw a distinction between subjective and objective time. The first is the time experienced or apprehended by the human mind, which can appear to go slow or fast with varying mental states – within the limits just discussed. The second is the time measured by such inanimate devices as clocks, oscillating crystals or vibrating atoms, and until this century it was an act of faith among scientists that whatever *we* thought, objective time flowed at a steady, unvarying rate. Not the least of the shocks produced by the Theory of Relativity was the discovery that this is simply not true.

Curiously enough, the ancient Egyptians might have found it easy to accept the relativity of time. Their first simple sundials had faces graduated in equal arcs, so that the lengths of their 'hours' necessarily varied during the day. When, some centuries later, they developed water-clocks which ran at a constant rate, they were so conditioned to the idea of variable time that they devoted great efforts to calibrating their clocks so that they agreed with their sundials! 'In the flow of water,' says Rudolf Thiel in his book, *And There Was Light* 'they had a direct image of steadily flowing time. But with extraordinary skill and ingenuity they artificially produced irregularity in a regular natural phenomenon, in order to make time flow in the only manner that seemed right to them; with the inconstancy of their sundials.'

The variability of Time is a natural and inevitable consequence of Einstein's discovery that Time and Space cannot be discussed separately, but are aspects of a single entity which he called Space-Time. Contrary to popular opinion, the arguments leading to this conclusion are not so abstruse and mathematical as to be beyond the layman; they are in fact so elementary as to be baffling in their very simplicity. (I wonder how often Einstein was infuriated by the phrase, 'Is *that* all there is to it!') The problem of explaining Relativity is like that of convincing an ancient Egyptian that his water clock was really superior to his sundial, or of persuading a medieval monk that people need not fall off the other side of a spherical Earth. Once preconceived ideas are cleared away, the rest is simple.

I have no intention of explaining Relativity here, since every public library contains its quota of popular books on the subject. (One of the very best, recently reissued after thirty-five years by G. Bell and Sons Ltd, is *Readable Relativity* by Clement V. Durell. How odd that the most celebrated literary relativist of today should have an almost identical surname.) Here, however, is what I hope may be a useful analogy:

In ordinary life, we are accustomed to divide space into three dimensions or directions, which we call Sideways, Forwards and Upwards. One of these directions is not quite on a par with the others, as anyone will find if he steps out of a tenth-floor window, but Forwards and Sideways are completely arbitrary ('relative'). They depend purely on the point of view of the individual observer;

if he turns, they turn with him.

When we look into the matter a little more closely, we find that even the direction we call Upwards is not as absolute as we usually assume. It changes constantly over the face of the Earth – a fact that has distressed early theologians attempting to locate Heaven. But even in one spot, it can have different apparent directions. When you are in a jet-liner during the take-off, you will feel the vertical tilt as you accelerate along the runway, and if your seat could swivel it would line itself up with a new set of axes. Your Upwards and Forwards are no longer the same as those of a man in the airport lounge; you both occupy the same region of space, but now divide it up in a slightly different way. Some of his horizontal has become some of your vertical.

In a roughly comparable manner, observers moving at differing speeds divide up Space-Time in slightly different proportions, so that one, to put it somewhat crudely, gets a little more time, and a little less space, than the other – though the sum total is always the same. (Adding time and space may sound like adding apples and oranges, but we won't worry about the elementary mathematical trick used to do it.) Thus the rate at which time flows in any system – inside a spaceship, for example – depends upon the speed with which that system is moving, and also upon the gravitational fields it is experiencing.

At normal speeds, and in ordinary gravitational fields, the time-distortion is absolutely negligible. Even in an artificial satellite whirling round the globe at 18,000 mph, a clock would lose only one tick in three billion. An astronaut making a single orbit round the Earth would have aged a millionth of a second less than his companions on the ground; the other effects of the flight would rather easily counterbalance this.

Only since 1959 has it been possible to demonstrate this incredibly tiny stretching of time at the modest speeds of terrestrial bodies. No man-made clock could do it, but thanks to a brilliant technique evolved by the German physicist Mössbauer we can now use vibrating atoms to measure time to an accuracy of considerably better than one part in a million million. Not, please note, one part in a million, but one part in a *million* million.

Let us pause for a moment to consider what this means, for it is another victory over Time – a metrical victory which the builders of the first sundials and water-clocks could scarcely have imagined. A clock accurate to one part in a million million, which is what Dr Mössbauer has (for certain applications) given us, would lose only one second in 30,000 years – a single tick between the first cave-painters of Lascaux and the first colonists of Mars. Such accuracy in the measurement of distance would enable us to notice if the Earth's diameter increased or decreased by the thickness of a bacterium.

Although this Time Stretching or Dilation effect is so tiny at ordinary speeds, it becomes large at extraordinary ones, and very large indeed as one approaches the velocity of light. In a spaceship travelling at 87 per cent of the speed of light, or 580,000,000 mph, time would be passing at only half the rate it flows on Earth. At 99.5 per cent of the speed of light – 667,000,000 mph – the rate would be slowed tenfold; a month in the spaceship would be almost a year on Earth. (Relativists will, I hope, forgive me for certain over-simplifications and hidden assumptions in these statements; everyone else, please ignore this parenthesis.)

The important point to note is that there would be absolutely no way in which the space-travellers could tell that anything odd was happening to them. Everything aboard the vehicle would appear to be perfectly normal – and indeed it would be. Not until they returned to Earth would they discover that far more time had elapsed there than in the speeding ship. This is the so-called Time Paradox which would allow, in principle at least, a man to come back to Earth centuries or millennia after he had left it, having himself aged only a few years. To anyone familiar with the Theory of Relativity, however, it is no paradox at all: it is merely a natural consequence of the structure of space and time.

The main application of this time-stretching effect is for flight to the stars, if this is ever achieved. Though such flights may last centuries, it will not seem so to the astronauts. Thus an inescapable by-product of long-range space-travel is travel into the future – one-way travel, of course. An interstellar voyager could return to his own Earth, but never to his own age.

That such an astonishing event is possible at all would have been flatly denied fifty years ago, but now it is an accepted axiom of science. This leads us to wonder if there may not be other ways in which Time could be stretched or distorted – ways which avoid the inconvenience of travelling several light-years.

I must say at once that the prospect does not look at all hopeful. In theory, oscillation or vibration could have a similar effect on time – but the rates involved would be so enormous that no material object could hold together under the strain. Since gravity, as well as speed, also affects the flow of time, this line of approach looks slightly more promising. If we ever learn to control gravity, we may also learn to control time. Once again, titanic forces would be required to produce minute time-distortions. Even on the surface of a White Dwarf star, where gravity is thousands of times more powerful than on Earth, it would require very accurate clocks to reveal that time was running slowly.

You will have noticed that the few known means of distorting time are not only exceedingly difficult to apply, but also work in the least useful direction. Though there are occasions when we would like to slow ourselves down with respect to the rest of the world, so that time appeared to go by in a flash, the reverse process would be far more valuable. There is no one who, at some moment or other, has not felt a desperate need for more time; often a few minutes – even a few seconds – would make the difference between life and death. Working against the clock would be no problem in a world where one could make the clock stand still, even if only for a while.

We have no idea how this might be done; neither the Theory of Relativity nor anything else gives us a single clue. But a real acceleration of time – not the subjective and limited one produced by drugs – would be of such great value that if it is at all possible we will one day discover how to attain and use it. A society in which the United Nations could get through an all-day emergency session while the rest of New York had its coffee-break, or in which an author could take an hour off to write an 80,000 word book, is difficult to imagine and would be rather hard on the nerves. It may not be desirable and is certainly not likely; but I dare not say that it is impossible.

Travelling into the future is the one kind of time-travel we all indulge in, at the steady speed of 24 hours every day. That we may be able to alter this rate does not, as we have seen, involve any scientific absurdities. In addition to high-speed space-voyaging, suspended animation may also allow us to travel down the centuries and see what the future holds in store, beyond the normal expectation of life.

But by time-travel, most people mean something considerably more ambitious than that. They mean going into the future and *coming back to the present again*, preferably with a complete list of stock market quotations. This, of course, implies travelling into the past – for from the point of view of the Future we are (were?) the Past; and this, we have already decided, is quite impossible.

I would be willing to state that seeing into the future – clearly a less ambitious project than actually visiting it – is equally impossible, were it not for the impressive amount of evidence to the contrary. There have always, of course, been prophets and oracles who claimed the ability to foretell the future; 'Beware the Ides of March' is perhaps the most famous of such predictions. In recent years the work of Professor Rhine at Duke University, and Dr Soal and his colleagues in England, has produced much more concrete proof of 'precognition' – though it is all in the form of statistics, for which most people have an instinctive distrust. In this case, the distrust may be justified; perhaps there is something fundamentally wrong with the mathematical analysis of the card-guessing experiments on which most claims for precognition are based. The whole subject is so complicated, and so loaded with prejudice and emotion, that I propose to tiptoe hastily away from it; if you want any more information, look up Rhine, J. B., in the card-index of your local library.

Whether the future can be known, even in principle, is one of the subtlest of all philosophical questions. A century and a half ago, when Newtonian mechanics had reached its greatest triumphs in predicting the movements of the heavenly bodies, the answer was a qualified ‘Yes’. Given the initial positions and velocities of all the atoms in the universe, an all-wise mathematician could calculate everything that would happen to the end of time. The future was predetermined down to the minutest detail, and therefore it could – in theory – be predicted.

We now know that this view is much too naïve, for it is based on a false assumption. It is *impossible* to specify the initial positions and velocities of all the atoms in the universe – to the absolute degree of accuracy such a calculation would require. There is an intrinsic ‘fuzziness’ or uncertainty about the fundamental particles, which means that we can never know exactly what they are doing at this moment – still less a hundred years hence. Though some events – eclipses, population statistics, perhaps some day even the weather – can be predicted with considerable accuracy, the mathematical road into the future is a narrow one and eventually peters out into the quagmire of Indeterminancy. If any seer or sibyl has in truth really obtained knowledge of the future, it is by some means not only unknown to present science, but flatly contravening it.

Yet we know so little about Time, and have made such scanty progress in understanding and controlling it, that we cannot rule out even such outrageous possibilities as limited access to the future. Professor J. B. S. Haldane once shrewdly remarked: ‘The Universe is not only queerer than we imagine – it is queerer than we can imagine.’ Even the Theory of Relativity may only hint at the ultimate queerness of Time.

In his poem, *The Future,* Matthew Arnold described man as a wanderer ‘born in a ship, On the breast of the river of Time’. Through all history, that ship has been drifting rudderless and uncontrolled; now, perhaps, he is learning how to start the engines. They will never be powerful enough to overcome the current; at the best, he may delay his departure, and get a better view of the lands around him, and the ports he has left for ever. Or he may speed up his progress, and start downstream more swiftly than the current would otherwise bear him. What he can never do is to turn back and revisit the upper reaches of the river.

And in the end, for all his efforts, it will sweep him with his hopes and dreams out into the unknown ocean:

As the pale waste widens around him –
As the banks fade dimmer away –
As the stars come out, and the night-wind

Brings up the stream
Murmurs and scents of the infinite Sea.

TWELVE

AGES OF PLENTY

The raw materials of civilization, as of life itself, are matter and energy, which we now know to be two sides of the same coin. For most of human history, and all of prehistory, only the most modest quantities of either were used by men. During the course of a year, one of our remote ancestors consumed about a quarter of a ton of food, half a ton of water and negligible quantities of hide, sticks, stones and clay. The energy he expended was that created by his own muscles, plus an occasional small contribution in the form of wood fires.

With the rise of technology, that simple picture has changed beyond recognition. The yearly consumption of the average American citizen is more than half a ton of steel, seven tons of coal and hundreds of pounds of metals and chemicals whose very existence was unknown to science a century ago. Every year, over *twenty tons* of raw materials are dug from the earth to provide modern man with the necessities – and luxuries – of life. No wonder that we hear warnings from time to time of critical shortages, and are told that within a few generations copper or lead may be added to the list of rare metals.

Most of us take little notice of these alarms, because we have heard them before – and nothing has happened. The unexpected discovery of huge oilfields on the sea beds has, for the time being, silenced the Cassandras of the petroleum industry, who have predicted that we would be running out of petrol by the end of this century. They were wrong this time – but in the slightly longer run, they will be right.

Whatever new reserves may be discovered, 'fossil fuels' such as coal and oil can last only for a few more centuries; then they will be gone for ever. They will have served to launch man's technological culture into its trajectors, by providing easily available sources of energy, but they cannot sustain civilization over thousands of years. For this, we need something more permanent.

Today, there can be little doubt that the long-term (and perhaps the short-term) answer to the fuel problem is nuclear energy. The weapons already now stockpiled by the major powers could run all the machines on earth for several years, if their energies could be used constructively. The warheads in the

American arsenals alone are equivalent to thousands of millions of tons of oil or coal.

It is not likely that fission reactions (those involving such heavy elements as thorium, uranium and plutonium) will play more than a temporary role in terrestrial affairs; one hopes not, for fission is the dirtiest and most unpleasant method of releasing energy that man has ever discovered. Some of the radio-isotopes from today’s reactors will still be causing trouble and perhaps injuring unwary archaeologists, a thousand years from now.

But beyond fission lies fusion – the welding together of light atoms such as hydrogen and lithium. This is the reaction that drives the stars themselves; we have reproduced it on earth, but have not yet tamed it. When we have done so, our power problems will have been solved for ever – and there will be no poisonous by-products, but only the clean ash of helium.

Controlled fusion is the supreme challenge of applied nuclear physics; some scientists believe it will be achieved in ten years, some in fifty. But almost all of them are sure that we will have some fusion power long before our oil and coal run out, and will be able to draw fuel in virtually unlimited quantities from the sea.

It may well be – indeed, at the moment it appears very likely – that fusion plants can be built only in very large sizes, so that no more than a handful would be required to run an entire country. That they can be made small and portable – so that they could be used to drive vehicles, for example – appears most improbable. Their main function will be to produce large quantities of thermal and electrical energy, and we will still be faced with the problem of getting this energy to the millions of places where it is needed. Existing power systems can supply our houses – but what about our automobiles and aircraft, in the Post-Petroleum Age?

The desirable solution is some means of storing electricity which will be at least ten, and preferably a hundred, times more compact than the clumsy and messy batteries that have not improved fundamentally since the time of young Tom Edison. This urgent need has already been mentioned in Chapter 3, in connection with electric automobiles, but there are countless other requirements for portable energy. Perhaps the forced draught of space technology will lead us fairly quickly to a light-weight power-cell, holding as much energy per pound as petrol; when we consider some of the other marvels of modern technology, it seems a modest enough demand.

A much more far-fetched idea is that we might be able to broadcast power from some central generating station, and pick it up anywhere on earth by means of a device like a radio receiver. On a limited scale, this is already possible, though only at great difficulty and expense.

Well-focused radio beams carrying up to 1,000 hp of continuous energy can now be produced and part of this energy could be intercepted by a large antenna system several miles away. Because of the inevitable spreading of the beam, however, most of its energy would be wasted, so the efficiency of the system would be very low. It would be like using a search-light, ten miles away, to illuminate a house; most of the light would splash over the surrounding landscape. In the case of a high-powered radio beam, the lost energy would not merely be wasteful – it would be quite dangerous, as the builders of long-range radars have already discovered.

Another fundamental objection to radio-power is that the transmitter would have to pump out the same amount of energy whether or not it was being used at the other end. In our present distribution systems, the central generating plant does not produce electricity until we call for it by switching on an appliance; there is ‘feedback’ from consumer to generator. It would be extremely difficult, though not impossible, to arrange this with a radio power system.

Beamed radio power seems impracticable, therefore, except for very special applications; it might be useful between satellites and space vehicles if they were close together and not changing their relative positions. It would be quite hopeless, of course, for moving vehicles – the very case where it is most badly needed.

Broadcast power, if it is ever achieved, must depend upon some principle or technology at present unknown. Fortunately, it is not something we must have – merely something that would be useful. If necessary, we will manage without it.

As pure, speculation, we should mention the possibility that other power sources may exist in the space around us, and that we may one day be able to tap them. Several are already known, but they are all extremely feeble or suffer from fundamental limitations. The most powerful is the radiation field of the Sun – that is, sunlight – and we are already using this to operate our space vehicles. The output of the solar hydrogen reactor is gigantic – about 500,000,000,000,000,000,000,000 hp – but by the time it reaches Earth the flood of energy has been drastically diluted by distance. A rough and easily remembered figure is that the energy of sunlight at sea-level is about 1 hp per square yard; it varies widely, of course, with atmospheric conditions. So far we have been able to convert about one-tenth of this energy into electricity (at a cost of a few thousand dollars per horsepower for present-day solar cells!), so a 10 hp automobile would require about 1,000 square yards of collecting surface – even on a bright, sunny day. This is hardly a practicable proposition.

We cannot tap the flood of solar energy profitably unless we move much closer to the Sun; even on Mercury, we could produce only about 1 hp of electrical energy per square yard of collecting surface. One day it may be possible to set up light-traps very close to the Sun*, and beam the resultant energy to the points where it is required. If fusion power is not forthcoming, we will be forced to take some such drastic step as this. But spaceships had better avoid those power-beams; they would be very effective death-rays.

All the other known energy sources are millions of times weaker than sunlight. Cosmic rays, for example, carry about as much energy as starlight; it would be much more profitable to build a moonbeam-powered engine than one driven by cosmic radiation. This may seem a paradox, in view of the well-known fact that these rays are often of enormous energy and can inflict severe biological damage. But the high energy rays (actually, particles) are so few and far between that their *average* power is negligible. If it were otherwise, we should not be here.

The Earth's gravitational and magnetic fields are sometimes mentioned as potential sources of energy, but these have serious limitations. You cannot draw energy out of a gravitational field without letting some heavy object – already placed at a convenient altitude – fall through it. This, of course, is the basis of hydro-electric power, which is an indirect way of using solar energy. The sun, evaporating water from the ocean, creates the mountain lakes whose gravitational energy we tap with our turbines.

Hydro-electric power can never provide more than a few per cent of the total energy needed by the human race, even if (which heaven forbid) every waterfall on the planet were funnelled into penstocks. All other ways of harnessing gravitational energy would involve the movement of matter on a very large scale: flattening mountains, for example. If we ever undertake such projects, it will be for quite other purposes than the generation of power, and the total operation will almost certainly leave us with a net energy loss. Before you can pull down a mountain, you have to break it to pieces.

The Earth's magnetic field is so extremely feeble (a toy magnet is thousands of times stronger) that it is not even worth considering. From time to time one hears optimistic talk of 'magnetic propulsion' for space vehicles, but this is a project somewhat comparable to escaping from Earth *via* a ladder made of cobwebs. Terrestrial magnetic forces are just about as tough as gossamer.

'Yet so much of the universe is indetectable to our senses, and so many of its energies have been discovered only during the last few moments of historic time, that it would be rash to discount the idea of still unknown cosmic forces. The concept of nuclear energy seemed nonsense only a lifetime ago, and even when it was proved to exist, most scientists denied that it could ever be tapped. There is considerable evidence that a flood of energy is sweeping through all the stars and planets in the form known as neutrino radiation (discussed in more detail in Chapter 9), which so far has practically defied all our powers of observation. So might Sir Isaac Newton, for all his genius, have failed to detect anything emerging from a radio antenna.

For terrestrial projects, it does not greatly matter whether or not the universe contains unknown and untapped energy sources. The heavy hydrogen in the seas can drive all our machines, heat all our cities, for as far ahead as we can imagine. If, as is perfectly possible, we are short of energy two generations from now, it will be through our own incompetence. We will be like Stone Age men freezing to death on top of a coal bed.

For most of our raw materials, as for our power sources, we have been living on capital. We have been exploiting the easily available resources – the high-grade ores, the rich lodes where natural forces have concentrated the metals and minerals we need. These processes took a billion years or more; in mere centuries, we have looted treasures stored up over aeons. When they are gone, our civilization cannot mark time for a few hundred million years until they are restored.

Once more, we will be forced to use our brains instead of our muscles. As Harrison Brown has pointed out in his book, *The Challenge of Man's Future*, when all the ores are exhausted we can turn to ordinary rocks and clays. 'One hundred tons of average igneous rock such as granite contains 8 tons of aluminium, 5 tons of iron, 1,200 pounds of titanium, 180 pounds of manganese, 70 pounds of chromium, 40 pounds of nickel, 30 pounds of vanadium, 20 pounds of copper, 10 pounds of tungsten, and 4 pounds of lead.'

To extract these elements would require not only advanced chemical techniques, but very considerable amounts of energy. The rock would first have to be crushed, then treated by heat, electrolysis and other means. However, as Harrison Brown also points out, a ton of granite contains enough uranium and thorium to provide energy equivalent to fifty tons of coal. All the energy we need for the processing is there in the rock itself.

Another almost limitless source of basic raw materials is the sea. A single cubic mile of sea water contains, suspended or dissolved, about 150,000,000 tons of solid material. Most of this (120,000,000 tons) is common salt, but the remaining 30,000,000 tons contains almost all the elements in impressive quantities. The most abundant is magnesium (about (18,000,000 tons) and its large-scale extraction from the sea during the Second World War was a great, and highly significant, triumph of chemical engineering. It was not, however, the first element to be obtained from sea-water, for the extraction of bromine in commercial quantities started as early as 1924.

The difficulty with ‘mining’ the sea is that that materials we wish to win from it are present in very low concentrations. That 18,000,000 tons of magnesium per cubic mile is an enormous figure (it would supply the world’s needs, at the present rate, for several centuries), but it is dispersed in 4 *billion* tons of water. Regarded as an ore, therefore, sea-water contains only four parts of magnesium per million; on land, it is seldom profitable to work rocks containing less than one part in a hundred of the commoner metals. Many people have been hypnotised by the fact that a cubic mile of sea-water contains about twenty tons of gold, but they would probably find richer paydirt in their own back-gardens.

Nevertheless, the great developments in chemical processing that have taken place in recent years – especially as a result of the atomic energy programme, where it became necessary to extract very small amounts of isotopes from much larger quantities of other materials – suggest that we may be able to work the sea long before we exhaust the resources of the land. Once again, the problem is largely one of power – power for pumping, evaporation, electrolysis. Success may come as part of a combined operation; the efforts underway in many countries to obtain drinkable water from the sea will produce enriched brines as a by-product, and these may be the raw materials for the processing plants.

One can imagine, perhaps before the end of this century, huge general-purpose factories using cheap power from thermonuclear reactors to extract pure water, salt, magnesium, bromine, strontium, rubidium, copper and many other metals from the sea. A notable exception from the list would be iron, which is far rarer in the oceans than under the continents.

If mining the sea appears an unlikely project, it is worth remembering that for more than seventy years we have been mining the atmosphere. One of the big, but now forgotten, worries of the nineteenth century was the coming shortage of nitrates for fertilizers; natural sources were running low, and it was essential to find some way of ‘fixing’ the nitrogen in the air. The atmosphere contains some 4,000 million million tons of nitrogen, or more than a million tons for every person on Earth, so if it could be utilised directly there would never be any fear of further shortages.

This feat was achieved, by several methods, in the opening years of this century. One process involves the brute-force ‘burning’ of ordinary air in a high-powered electric arc, for at very high temperatures the nitrogen and oxygen in the atmosphere will combine. This is an example of what can be done when cheap power is available (the Norwegians were able to pioneer this process, thanks to their early lead in hydroelectric generation) and it is perhaps a pointer for the future.

The really lavish use of concentrated energy sources for mining has hardly begun, but as already mentioned in Chapter 9, the Russians have been experimenting with high-frequency arcs and rocket jets to break up or drill rocks too tough to be worked in any other way. And ultimately, of course, there is the prospect of using nuclear explosions for large-scale mining, if the problems of radio-active contamination can be avoided.

When we consider that our deepest mines (now passing the 7,000-foot level) are mere pin-pricks on the surface of our 8,000-mile diameter planet, it is obviously absurd to talk about fundamental shortages of *any* element or mineral. Within five – certainly ten – miles of us lie all the raw materials we can ever use. We need not go after them ourselves; mining by human workers is, none too soon, disappearing from beneath the face of the earth. But machines can operate quite happily in temperatures of several hundred degrees and at pressures of scores of atmospheres, and this is just what the robot moles of the near future will be doing, miles beneath our feet.

Of course it is far too difficult, and too expensive, to work seams several miles down – with existing techniques. Very well: we will have to discover wholly new methods, as the oil-drillers and the sulphur miners have already done. The projects discussed in Chapter 9 will be forced upon us by sheer necessity as well as scientific curiosity.

Now let us widen our horizons somewhat. So far, we have been considering only *this* planet as a source of raw materials, but the Earth contains only about three-millionths of the total matter in the Solar System. It is true that more than 99.9 per cent of that matter is in the Sun, where at first sight it would appear to be out of reach, but the planets, satellites and asteroids contain between them the mass of 450 Earths. By far the greatest part of this is in Jupiter (318 times the mass of Earth) but Saturn, Uranus and Neptune also make sizeable contributions. (95, 15 and 17 Earths, respectively.)

In view of the present astronomical cost of space-travel (very approximately $1,000 per pound of payload for even the simplest orbital missions) it may seem fantastic to suggest that we will ever be able to mine and ship megatons of raw materials across the Solar System. Even gold could hardly pay its way, and only diamonds would show a profit.

This view, however, is coloured by today’s primitive state of the art, which depends upon hopelessly inefficient techniques. It is something of a shock to realize that, if we could use the energy really effectively, it would require only about ten pence worth of chemical fuel to lift a pound of payload completely clear of the Earth – and perhaps one or two pence to carry it from Moon to Earth. For a number of reasons, these figures represent unattainable ideals; but they do indicate how much room there is for improvement. Some studies of nuclear propulsion systems suggest that, even with techniques we can imagine today, space-flight need be no more expensive than jet transportation; as far as inanimate cargoes are concerned, it may be very much cheaper.

Consider first the Moon. We know nothing as yet about its mineral resources, but they must be enormous, and some of them may be unique. Because the Moon has no atmosphere, and has a rather weak gravitational field, it would be quite feasible to project material from its surface ‘down’ to Earth by means of electrically powered catapults or launching tracks. No rocket fuel would be needed – only a few pence worth of electrical energy per pound of payload. (The capital cost of the launcher would, of course, be very great; but it could be used an indefinite number of times.)

It would thus be theoretically possible, as soon as large-scale industrial operations commence on the Moon, to ship back lunar products on a considerable scale, aboard robot freighters which could glide to assigned landing areas after they had dissipated their 25,000 mph re-entry speed in the upper atmosphere. The only rocket fuel used in the entire process would be negligible amounts for steering and altitude control; all the energy would be provided by the fixed power-plant of the Moon-based launcher.

Going still farther afield, we know that there are enormous quantities of metal (much of it the highest grade of nickel-iron) floating round the Solar System in the form of meteorites and asteroids. The largest asteroid, Ceres, has a diameter of 450 miles, and there may be thousands over a mile across. It is interesting to note that a single iron asteroid, 300 yards in diameter, would supply the world’s present needs for a year.

What makes the asteroids particularly promising as a source of raw materials is their microscopic gravity. It needs practically no energy to escape from them; a man could jump off one of the smaller asteroids with ease. When nuclear propulsion systems have been perfected, it would be practical to nudge at least smaller asteroids out of their orbits and inject them into paths that would lead, after a year or so, to the vicinity of Earth. Here they might be parked in orbit until they were cut up into suitably sized pieces; alternatively, they might be allowed to fall directly to Earth.

This last operation would require almost no consumption of fuel, as the Earth’s gravitational field would do all the work. It would, however, require extremely accurate and completely reliable guidance, for the consequences of error would be too terrible to contemplate. Even a very small asteroid could erase a city, and the impact of one containing a year's supply of iron would be equivalent to a 10,000 megaton explosion. It would make a hole at least ten times as large as Meteor Crater – so perhaps we had better use the Moon, not the Earth, for a dumping-ground.

If we ever discover means of controlling or directing gravitational fields (a problem discussed in Chapter 5) such astronomical engineering operations would become much more attractive. We might then be able to absorb the enormous energy of a descending asteroid and use it profitably, as today we use the energy of falling water. The energy would be an additional bonus, to be added to the value of the iron mountain we had gently lowered to Earth. Although this idea is the purest fantasy, no project which obeys the laws of the conservation of energy should be dismissed out of hand.

Lifting material from the giant planets is a very much less attractive proposition than mining the asteroids. The huge gravitational fields would make it difficult and expensive, even given unlimited amounts of thermo-nuclear power – and without this assumption, there is no point in discussing the matter. In addition, the Jupiter-type worlds appear to consist almost entirely of valueless light elements such as hydrogen, helium, carbon and nitrogen; any heavier elements will be locked up thousands of miles down inside their cores.

The same arguments apply, even more strongly, to the Sun. In this case, however, there is a factor which we may one day be able to use to our advantage. The material in the Sun is in the plasma state – that is, it is at such a high temperature that its atoms are all electrified or ionized. Plasmas conduct electricity far better than any metals, and their manipulation by magnetic fields is the basis of the important new science of magneto-hydrodynamics – usually, for obvious reasons, referred to as MHD. We are now using many MHD techniques in research and industry, to produce and contain gases at temperatures of millions of degrees, and we can observe similar processes in action on the Sun, where the magnetic fields around sunspots and flares are so intense that they hurl Earth-sized clouds of gas thousands of miles high in defiance of the solar gravity.

Tapping the Sun may sound a fantastic conception, but we are already probing its atmosphere with our radio beams. Perhaps one day we may be able to release or trigger the titanic forces at work there, and selectively gather what we need of its incandescent substance. But before we attempt such Promethean exploits, we had better know exactly what we are doing.

Having, in imagination, raided the Solar System in the search for raw materials, let us come back to Earth and explore a completely different line of thought. It may never be really necessary to go beyond our own planet for anything we need – for the time will come when we can create any element, in any quantity, by nuclear transmutation.

Until the discovery of uranium fission in 1939, practical transmutation remained as much a dream as it had been in the days of the old alchemists. Since the first reactors started operating in 1942, substantial amounts (to be measured in tons) of the synthetic metal plutonium have been manufactured, and vast quantities of other elements have been created as often unwanted and embarrassingly radio-active by-products.

But plutonium, with its overwhelmingly important military application, is a very special case, and everyone is aware of the cost and complexity of the plants needed to manufacture it. Gold is cheap by comparison, and synthesizing common metals like lead or copper or iron seems about as probable as mining them from the Sun.

We must remember, however, that nuclear engineering is in roughly the same position as chemical engineering at the beginning of the nineteenth century, when the laws governing reactions between compounds were just beginning to be understood. We now synthesize, on the largest scale, drugs and plastics which yesterday's chemists could not even have produced in their laboratories. Within a few generations, we will surely be able to do the same thing with the elements.

Starting with the simplest element hydrogen (one electron revolving around one proton) or its isotope deuterium (one electron revolving round a nucleus of a proton plus a neutron) we can 'fuse' atoms together to make heavier and heavier elements. This is the process operating in the Sun, as well as in the H-bomb; by various means, four atoms of hydrogen are combined to make one of helium, and in the reaction enormous quantities of energy are released. (In practice, the third element in the Periodic Table, lithium, is also employed.) The process is extremely difficult to start, and still harder to control – but it is only the very first step in what might be christened 'nuclear chemistry'.

At even higher pressures and temperatures than those produced in today's thermonuclear explosions or fusion devices, the helium atoms will themselves combine to form heavier elements; this is what happens in the cores of stars. At first, these reactions release additional energy, but when we reach elements as heavy as iron or nickel the balance shifts and extra energy has to be supplied to create them. This is a consequence of the fact that the heaviest elements tend to be unstable and break down more easily than they fuse together. Building up elements is rather like piling up a column of bricks; the structure is stable at first, but after a while it is liable to spontaneous collapse.

This is, of course, a very superficial account of nuclear synthesis; a detailed description of what happens inside stars is given in Fred Hoyle's *Frontiers of*

Astronomy. You will find there that the temperatures involved are between 1,000 and 5,000 million degrees, and the pressures millions of *billions* of atmospheres, which hardly makes this line of attack look promising.

But there are other ways of starting reactions, besides heat and pressure. The chemists have known this for many years; they employ catalysts which speed up reactions or make them take place at far lower temperatures than they would otherwise do. Much of modern industrial chemistry is founded on catalysts (*vide* the 'cat crackers' of the oil refineries) and the actual composition of these is often a closely guarded trade secret.

Are there nuclear, as well as chemical catalysts? Yes: in the Sun, carbon and nitrogen play this role. There may be many other nuclear catalysts, not necessarily elements. Among the legions of misnamed fundamental particles which now perplex the physicist – the mesons and positrons and neutrinos – there may be entities that can bring about fusion at temperatures and pressures that we can handle. Or there may be completely different ways of achieving nuclear synthesis, as unthinkable today as was the uranium reactor only thirty years ago.

The seas of this planet contain 100,000,000,000,000,000 tons of hydrogen and 20,000,000,000,000 tons of deuterium. Soon we will learn to use these simplest of all atoms to yield unlimited power. Later – perhaps very much later – we will take the next step, and pile our nuclear building blocks on top of each other to create any element we please. When that day comes, the fact that gold, for example, might turn out to be slightly cheaper than lead will be of no particular importance.

This survey should be enough to indicate – though not to prove – that there need never be any permanent shortage of raw materials. Yet Sir George Darwin's prediction (page 101) that ours would be a Golden Age compared with the aeons of poverty to follow, may well be perfectly correct. In this inconceivably enormous universe, we can never run out of energy or matter. But we can all too easily run out of brains.

THIRTEEN

ALADDIN'S LAMP

Men, unlike planets, cannot thrive on pure energy and a few simple chemical compounds. Ever since the gates of Eden clanged shut with such depressing finality, the human race has been engaged in a ceaseless struggle for food, shelter and the material necessities of life. More than 2 million million man-years have been expended in this age-long battle with Nature, and only in the last four or five of the 50,000 generations of mankind has the burden shown signs of lifting.

The rise of modern science, and in particular the advent of mass-production and automation, is of course responsible for this; but even these techniques are only pointers towards far more revolutionary methods of manufacture. The time may come when the twin problems of production and distribution are solved so completely that every man can, almost literally, possess anything he pleases.

To see how this may be achieved, we must forget all about our present ideas of manufacturing processes and go back to fundamentals. Any object in the physical world is completely specified or described by two factors: its composition and its shape or pattern. This is quite obvious in a simple case; such as a one-inch cube of pure iron. Here, the two phrases 'pure iron' and 'one-inch cube' provide a complete definition of the object, and there is no more to be said. (To the first approximation, at least: an engineer would like to know the dimensional tolerances, a chemist the precise degree of purity, a physicist the isotopic composition.) From this brief five-word description, anyone with the correct equipment and skills could make a perfect copy of the object specified.

This is true, in principle, for much more complicated objects, such as radio-sets, automobiles or houses. In such cases it is necessary to have not only verbal descriptions but plans or blue-prints – or their modern equivalent, pulses stored on magnetic tape. The tape which controls an automated production line carries, in suitably coded form, a complete physical description of the object being manufactured. Once the master tape has been made, the act of creation is finished. What follows is a mechanical process of replication, like printing a sheet of letter-press when the type has been set up.

During the last few years, more and more complicated artifacts have been produced in this wholly automatic manner, though the initial cost of equipment (and skill) is so high that the process is worth while only where there is a demand for enormous numbers of copies. It requires a specialised machine to manufacture one particular type of object; a bottle-making machine cannot switch to cylinder heads. A completely general-purpose production line, able to produce *anything* merely from a change of instructions, is inconceivable in terms of today's techniques.

It may seem inconceivable in terms of any technique, because (perhaps most) of the artifacts we employ and the materials we consume in everyday life are so complicated that it is impossible to specify them in explicit detail. Anyone who doubts this should try to write out the *complete* description of a suit of clothes, a pint of milk or an egg so that an omnipotent entity who had never seen any of these things could reproduce them perfectly.

Perhaps a specification for a suit might be just possible today, if it were made of synthetic fabric; but not if it were made of organic materials like wool or silk. The pint of milk is a challenge that the biochemists of the future may be able to meet, but I shall be very surprised if, in this century, we have a complete analysis of all the fats, proteins, salts, vitamins and heaven knows what else that go into this most comprehensive of foods. As for an egg – this represents an even higher order of complexity, both in chemistry and structure; most people would deny that there is the slightest possibility of ever creating such an object, except by the traditional methods.

Yet let us not be discouraged. In Chapter 7, when discussing the possibility of instantaneous transportation, we considered a device that would scan solid objects atom by atom to make a 'recording' that could ultimately be played back, either at the same spot or at a distance. Though such a device cannot be realized, or even remotely envisaged, in terms of today's science, no philosophical contradictions or absurdities are raised if we suppose its operations limited to fairly simple, inanimate objects. It is worth remembering that an ordinary camera can, in a thousandth of a second, make a 'copy' of a picture containing millions of details. This would indeed have been a miracle to an artist of the Middle Ages. The camera is a general-purpose machine for reproducing, with a considerable though not complete degree of accuracy, *any* pattern of light, shade and colour.

Today we have devices which can do very much more than this, though even the names of most of them are not known to the general public. Neutron activation analysers, infra-red and X-ray spectrometers, gas chromatographs can perform, in a matter of seconds, detailed analyses of complex materials over which the chemists of a generation ago could have laboured in vain for weeks. The scientists of the future will have far more sophisticated tools, that can lay bare all the secrets of any object presented to them and automatically record all its characteristics. Even a highly complex object could be completely specified on a modest amount of recording medium; you can put the Ninth Symphony on a few hundred feet of tape, and this involves much more information or detail than, say, a watch.

It is the 'playback', from recording to physical reality, which is rather difficult to visualize, but it may surprise many people to learn that this has already been achieved for certain small-scale operations. In the new technique of micro-electronics, solid circuits are built up by controlled sprays of atoms, literally layer by layer. The resulting components are often too tiny to be seen by the naked eye (some are even invisible under high-powered microscopes) and the manufacturing process is of course automatically controlled. I would like to suggest that this represents one of the first primitive breakthroughs towards the type of production we have been trying to imagine. As the punched-tape of the Jacquard loom controls the weaving of the most complex fabrics (and has done so for 200 years) so we may one day have machines that can lay a three-dimensional warp and woof, organizing solid matter in space from the atoms upwards. But for us to attempt the design of those machines now would be rather like the imagined efforts of Leonardo da Vinci (page 92) to make a TV system.

Leaping lightly across some centuries of intense development and discovery, let us consider how the Replicator would operate. It would consist of three basic parts – which we might call Store, Memory and Organizer. The Store would contain, or would have access to, all the necessary raw materials. The Memory would contain the recorded instructions specifying the manufacture (a word which would then be even more misleading than it is today) of all the objects within the size, mass and complexity limitations of the machine. Within these limits, it could make anything – just as a phonograph can play any conceivable piece of music that is presented to it. The physical size of the Memory could be quite small, even if it had a large built-in library of instructions for the most commonly needed artifacts. One can envisage a sort of directory, like a Sears-Roebuck catalogue, with each item indicated by a code number which could be dialled as required.

The Organizer would apply the instructions to the raw material, presenting the finished product to the outside world – or signalling its distress if it had run out of some essential ingredient. Even this might never happen, if the transmutation of matter ever becomes possible as a safe, small-scale operation, for then the Replicator might operate on nothing but water or air. Starting with the simple elements, hydrogen, nitrogen and oxygen, the machine would first synthesize higher ones, then organize these as requested. A rather delicate and fail-safe mass-balancing procedure would be necessary, otherwise the Replicator would produce, as a highly unwanted by-product, rather more energy than an H-bomb. This could be absorbed in the production of some easily disposable ‘ash’ such as lead or gold.

Despite what has been said earlier about the appalling difficulty of synthesizing higher organic structures, it is absurd to suppose that machines cannot eventually create any material made by living cells. Any last-ditch Vitalists who still believe this are referred to Chapter 18, where they will discover why inanimate devices can be fundamentally more efficient and more versatile than living ones – though they are very far from being so at the present stage of our technology. There is no reason to suppose, therefore, that the ultimate Replicator would not be able to produce any food that men have ever desired or imagined. The creation of an impeccably prepared *filet mignon* might take a few seconds longer, and require a little more material, than that of a drawing-pin, but the principle is the same. If this seems astonishing, no one today is surprised that a hi-fi set can reproduce a Stravinsky climax as easily as the twang of a tuning fork.

The advent of the Replicator would mean the end of all factories, and perhaps all transportation of raw materials and all farming. The entire structure of industry and commerce, as it is now organized, would cease to exist. Every family would produce all that it needed on the spot – as, indeed, it has had to do throughout most of human history. The present machine era of mass-production would then be seen as a brief interregnum between two far longer periods of self-sufficiency, and the only valuable item of exchange would be the matrices, or recordings, which had to be inserted into the Replicator to control its creations.

No one who has read thus far will, I hope, argue that the Replicator would itself be so expensive that nobody could possibly afford it. The prototype, it is true, is hardly likely to cost less than £1,000,000,000,000 spread over a few centuries of time. The second model would cost nothing, because the Replicator’s first job would be to produce other Replicators. It is perhaps relevant to point out that in 1951 the great mathematician, John von Neumann, established the important principle that a machine could always be designed to build any describable machine – including itself. The human race has squalling proof of this several hundred thousand times a day.

A society based on the Replicator would be so completely different from ours that the present debate between Capitalism and Communism would become quite meaningless. All material possessions would be literally as cheap as dirt. Soiled handkerchiefs, diamond tiaras, Mona Lisas totally indistinguishable from the original, once-worn mink stoles, half-consumed bottles of the most superb champagnes – all would go back into the hopper when they were no longer required. Even the furniture in the house of the future might cease to exist when it was not actually in use.

At first sight, it might seem that nothing could be of any real values in this Utopia of infinite riches – this world beyond the widest dreams of Aladdin. This is a superficial reaction such as might be expected from a tenth-century monk if you told him that one day every man could possess all the books he could possibly read. The invention of the printing press has not made books less valuable, or less appreciated, because they are now the commonest instead of the rarest of objects. Nor has music lost its charms, now that any amount can be obtained at the turn of a switch.

When material objects are all intrinsically worthless, perhaps only then will a real sense of values arise. Works of art would be cherished because they were beautiful, not because they were rare. Nothing – no 'things' – would be as priceless as craftsmanship, personal skills, professional services. One of the charges often made against our culture is that it is materialistic. How ironic it will be, therefore, if science gives us such total and absolute control over the material universe that its products no longer tempt us, because they can be too easily obtained.

It is certainly fortunate that the Replicator, if it can ever be built at all, lies far in the future, at the end of many social revolutions. Confronted by it, our own culture would collapse speedily into sybaritic hedonism, followed immediately by the boredom of absolute satiety. Some cynics may doubt if any society of human beings could adjust itself to unlimited abundance and the lifting of the curse of Adam – a curse which may be a blessing in disguise.

Yet in every age, a few men have known such freedom, and not all of them have been corrupted by it. Indeed, I would define a civilized man as one who can be happily occupied for a lifetime even if he has no need to work for a living. This means that the greatest problem of the future is civilizing the human race; but we know that already.

So we may hope, therefore, that one day our age of roaring factories and bulging warehouses will pass away, as the spinning-wheel and the home-loom and the butter churn passed before them. And then our descendants, no longer cluttered up with possessions, will remember what many of us have forgotten – that the only things in the world that really matter are such imponderables as beauty and wisdom, laughter and love.

FOURTEEN

INVISIBLE MEN, AND OTHER PRODIGIES

Though this confession leaves me thoroughly dated, back there with Rin-Tin-Tin and Mary Pickford, for me one of the big moments in movies was when Claude Rains unwrapped the bandages around his head – and there was nothing inside them. The idea of invisibility, with all the powers it would bestow upon anyone who could command it, is eternally fascinating; I suspect that it is one of the commonest of private daydreams. But it is a long time since it has appeared in adult science-fiction, because it is a little too naïve for this sophisticated age. It smacks of magic, which is now very much out of fashion.

Yet invisibility is not one of those concepts that involve an obvious violation of the laws of nature; on the contrary, there are plenty of objects that cannot be seen. Most gases are invisible; so are some liquids and a few solids, in the right circumstances. I have never had the privilege of looking for a large diamond in a tumbler of water, but I *have* searched for a contact lens in a bath, and that's as near to invisibility as I wish to get. Most of us have seen those arresting photos of workmen carrying large plate-glass windows; when glass is clean, and coated with an anti-reflection layer, it is almost as impossible to see as air.

This gives the fantasy writer (and in *The Invisible Man*, Wells was writing fantasy, not science-fiction) an easy way out. His hero has 'merely' to invent a drug which gives his body the same optical properties as air, and he will promptly become invisible. Unfortunately – or luckily – this cannot be done, and it is easy to show why.

Transparency is a most unusual property of a few exceptional substances, arising from the internal disposition of their atoms. If their atoms were arranged differently, they would no longer be transparent – and they would no longer be the same substances. You cannot take any compound at random and chemically torture it into transparency. And even if you could do so in one particular case, this would hardly help you to become an Invisible Man, for there are literally billions of separate and unbelievably complex chemical compounds in the human body. I doubt if the human species would last long enough to run the necessary research programme on each one of these compounds.

Moreover, the essential properties of many (if not most) depend upon the fact that they are *not* transparent. This is obvious in the case of the light-sensitive chemicals at the back of the eye, upon which we rely for our vision. If they no longer trapped light, we would be unable to see; and if our flesh was transparent, the eye would be unable to function because it would be flooded with radiation. You can't build a camera out of clear glass.

Less obvious is the fact that myriads of the biochemical reactions upon which life depends would be thrown utterly out of balance, or would cease altogether, if the molecules taking part in them were transparent. A man who achieved invisibility by drugs would not only be blind; he would be dead.

We need a more subtle approach to the problem, and several possibilities suggest themselves. Some have already been explored by Nature; if a thing can be done, she usually does it, sooner or later. There are many circumstances where camouflage is just as good as invisibility, and may even be better. Why go to the trouble of achieving genuine invisibility, if you can persuade those who look at you that you are something else? Poe's *The Purloined Letter* and Chesterton's *The Invisible Man* are interesting variation on this theme. In the lesser-known Chesterton story, a man is murdered in a house which all observers swear has not been entered. 'Then who made these footprints in the snow?' asks Father Brown with his usual egregious innocence. Nobody has noticed the postman – though everybody has *seen* him …

Many insects and land animals have developed remarkable powers of camouflage, but their disguise, being fixed, is effective only in the right surroundings; it may be worse than useless in others. The greatest masters of deception, who can change their appearance to fit their background, are to be found not on the land but in the sea. Flatfish and cuttlefish have an almost unbelievable control over the hues and patterns of their bodies, and are able to change colour within a few seconds when the need arises. A plaice lying on a chequer-board will reproduce the same pattern of black and white squares on its upper surface, and is even reputed to make a creditable attempt at a Scots tartan.

The ability to match the scene behind you would be a kind of pseudo-transparency, but it is obvious that it could only fool observers looking at you from a single direction. It works with the flatfish simply because it *is* flat and is trying to hide itself from predators swimming above it. The same trick would not work anything like so well in the open water, though it is still worth trying; this is why many fish are dark-coloured on the upper parts of their bodies, and light-coloured beneath. It minimises their visibility from above and from below.

No conceivable optical or TV system could transmit a picture of the background through a solid body in such a way that it was invisible from more than a very limited number of viewpoints. You can prove this by setting up – mentally – a complicated experiment that no one is ever likely to try in practice. It is the electronic equivalent of what the flatfish attempts to do, when it is placed on a chequer-board.

Imagine a man between two sandwich boards which are really large TV screens. He also has two cameras, one pointing to the front and the other to the rear. The forward-looking camera feeds a picture to the screen behind him, and vice versa.

If the (full colour!) TV circuits were perfectly adjusted, then the man would be effectively invisible from two points of view – one directly behind him, and one directly in front of him. Observers at these points would think that they were looking at some distant background, but part of it – the area covering the man – would actually be an image that precisely matched the reality. The slightest change of viewpoint would destroy the illusion; the TV picture would appear too big or too small, or would not fit its background, giving an effect like an out-of-adjustment Cinerama panel.

It is obvious that such an ‘image-transmission’ type of invisibility would be hopelessly limited, and I can think of only one story that has employed it. Back in the 1930s good old *Amazing Stories* published a tale featuring a coffin-sized glass box composed of prisms refracting the scene behind it, and containing a hollow interior within which a man could hide. Anyone observing the box would think that he was looking through an empty glass case, when he was really looking ‘round’ an occupied one. The idea is ingenious – and might even work on a small scale, to the convenience of spies and smugglers. For though it would be impossible to transmit an image through the box so that it appeared undistorted to observers with different viewpoints, in this instance a considerable amount of distortion would be acceptable and indeed expected. I hand the problem over to the optical experts; certainly it does not help us much in the quest for general invisibility.

Another now out-moded fictional method of achieving invisibility is by means of vibrations. Today we know much more about vibrations than we did a generation ago when, with a Capital V, they were part of the stock-in-trade of every spiritualist and medium. Radio, sonar, infra-red cookers, ultrasonic washers and the rest have brought them firmly down to earth, and we no longer expect them to produce miracles.

Vibrational invisibility is, however, little more plausible than the naive chemical variety peddled by Wells. It is based on a familiar analogy; everyone knows how the blades of an electric fan vanish when the motor gets up to speed. Well, suppose all the atoms of our bodies could be set vibrating or oscillating at a sufficiently high frequency …

The analogy is, of course, fallacious. We don't see *through* the fan blades, but past them; at every moment some of the background is uncovered, and at high enough speeds persistence of vision gives us the impression that we have a continuous view. If the fan blades overlapped, they would remain opaque – no matter how fast they were spinning.

And there is another unfortunate complication. Vibration means heat – in fact it *is* heat – and our molecules and atoms are already working as fast as we can take. Long before a man could be vibrated into invisibility, he would be cooked.

The situation does not look promising; the Cloak of Invisibility appears to be a dream beyond scientific realization. Yet now comes a surprise; perhaps we have been approaching the problem from the wrong angle. *Objective* invisibility may well be impossible – but *subjective* invisibility is possible, and has often been publicly demonstrated.

An expert hypnotist can persuade a subject not to see a certain person, and such is the power of the mind that the subject may be unable to do so even if that person is standing in full view. The subject will go to extraordinary lengths to 'explain away' the invisible man even when the latter tries to prove that he is present: the individual under hypnosis may eventually get hysterical if, for example, he sees what he believes are unattached articles of furniture moving around the room.

This fact is almost as amazing as genuine invisibility would be, and it suggests that, in the right circumstances and under appropriate influences (airborne drugs, subliminal suggestion, diversion of attention – to mention a few ideas) a person or object might be made effectively invisible to a fairly large group of people who were quite sure that they were in full possession of their senses. I advance this idea with some diffidence; but I have a hunch that *if* invisibility is ever achieved, it will be along these lines. It won't be done by drugs, optical devices or vibrations.

There is, however, a more-than-adequate substitute for invisibility, at least in fiction. An invisible man could be detected and trapped in many ways; not so a – shall we say? – *impalpable* one. Given the choice between invisibility and the power to walk through walls, I know which would be preferred by most people.

Several science-fiction writers (notably Will Jenkins, *alias* Murray Leinster) have made valiant efforts to put matter penetration on a rational basis; the argument usually runs as follows:

So-called 'solid' matter is really almost all empty space – just specks of electricity in an enormous void. The spaces inside the atoms are, proportionately, as great as those between the planets and stars. Just as two solar systems, or even two galaxies, can pass right through each other without a single physical collision taking place, so two solids could interpenetrate – if only we knew just how to make them.

About forty years ago, the ingenious Murray Leinster used an analogy which has stuck in my mind ever since. Two packs of cards can be passed through each other with little trouble or resistance, if they are kept parallel. Shuffle them higgledy-piggledy so that they point in all directions, and it's impossible. What we want, therefore, is some polarizing field that will align or orientate all the atoms in a body; if we can do this, then two solids can slip through each other like parallel packs of cards.

The argument was good enough for a 1935 *Astounding Stories*, but I am afraid that it will not convince this *blasé* generation. It is quite true that solar systems and galaxies can interpenetrate without actual physical collision, but the experience leaves an indelible mark on both participants. Though the suns and planets concerned may not come within millions of miles of each other, their gravitational tugs swing them into completely new orbits. And when two galaxies collide, the reaction between their tenuous clouds of interstellar gas produces the greatest outbursts of energy yet discovered in this universe – titanic explosions of radio power that we have been able to detect 10 thousand million light-years away.

In much the same way, if two objects passed through each other, the forces between their atoms and molecules would produce so many changes that each would be altered out of recognition. Gases and liquids can interpenetrate because they have no (or very little) internal structure; they are amorphous and no amount of shuffling makes any difference to them. Chaos remains chaos however much you shake it up. But all solids have an internal architecture which may be exceedingly complex, and exists on at least two levels – microscopic and molecular. That structure is maintained by electric and other forces; if you alter those forces, the body becomes something else – and the process cannot be reversed. Anyone who doubts this might try to unscramble an egg; this would be a very simple problem compared with restoring to their original form two solids that had interpenetrated.

There is, however, another possible road through matter – a tortuous and badly signposted road, for it leads us into the Fourth Dimension. Let us pluck up our courage and, ignoring the gibberings and eldritch shrieks from the mist on either side, strike out along this dubious path.

Actually, all the occultism and nonsense can be removed from the subject by a simple trick of semantics. In this context, 'dimension' means nothing more than 'direction', so we will use the latter word, which sets no bells jangling in the subconscious and rouses no memories of H. P. Lovecraft, Arthur Machen or Madame Blavatsky.

We all know what the word ‘direction’ means, and it is a fact of experience that in our normal everyday world any position or location can be completely specified by three directions, or co-ordinates, as the mathematician calls them. We might, in a convenient but completely arbitrary manner, label North-South as ‘The First Direction’, East-West as ‘The Second Direction’ and Up-Down as ‘The Third Direction’. The order could be changed around, and it doesn’t matter in the least which direction (or dimension) is First, Second or Third; the important point is that there are only three of them. No one has yet discovered any place which cannot be reached (in principle, at least) by a movement along one or more of directions One, Two and Three.

Although our Universe has only three directions, it is possible to imagine that there are more, but that for some reason our senses are unable to perceive them. Geometries are then conceivable as much ‘higher’, or more complex, than solid geometry as that is higher than plane geometry. We can speak of, even if we cannot visualize, the sequence of the one-directional straight line, the two-directional square, the three-directional cube – and the four-directional hypercube, known as a tesseract. The properties of this figure are fascinating and quite easily understood (its ‘faces’ consist of eight cubes, just as the faces of a cube consist of six squares), but to investigate them in any detail would be a digression which I must reluctantly forgo. I have, however, a soft spot for the tesseract; my very first TV engagement was a *live*, twenty-minute lecture on its properties, illustrated by home-made wire models. After that baptism of fire, all later TV programmes have been child’s-play.

The best way of getting to grips with the Fourth Direction is to take a step downwards into a two-directional world. It is not hard to conceive of a flat universe in which there is no such direction as height – a plane world, like that sandwiched between two sheets of glass infinitely close together. Call it Flatland;* if it had rational inhabitants, they would be familar with the figures of plane geometry – lines, circles, triangles – but would be quite unable to imagine such incredible entities as spheres or cubes or pyramids.

In Flatland, any closed curve – a circle, for example – would *completely* enclose a space. There would be no way into it, except by breaking or penetrating the curve. The vaults of the Bank of Flatland could be simple squares, and their contents would be perfectly secure.

Yet to beings like ourselves, capable of movement through the third direction of height, those bank vaults would be wide open. Not only could we look into them; we could reach into them and remove their contents, lifting them over the ‘wall’ and dropping them back into Flatland to present the local police with a most disturbing and inexplicable problem. A sealed room would have been burgled – yet no one and nothing had passed through its walls.

The analogy is now obvious, when we extend it to our own universe. There could be no enclosed spaces in our three-directional world, to a being capable of movement through a fourth direction. (Note that he need travel only a minute fraction of an inch in this direction, just as we need jump only a hair’s breadth to hop over the Flatlanders’ walls.) He could remove the contents of an egg without breaking the shell, carry out operations without leaving a scar, walk not through but *past* the walls of a locked room. Any law-abiding citizen can imagine an endless series of other interesting possibilities.

I do not think that we can fault the logic of this argument, even though Flatland itself becomes a little dubious when we investigate its physics. A fourth direction of space may indeed exist, though it will be very hard to find. (We are not concerned here, by the way, with the fact that Time is often referred to as a fourth dimension. We are discussing only *spacial* dimensions; anyone who wants to make the issue unnecessarily complicated by bringing in Time had better call it the Fifth Dimension, to keep it apart from the four we are trying to cope with.)

Another possibility is that, even if a fourth direction or dimension of space does not exist in Nature, we may be able to create such an extension artificially. Only a very little is needed, after all: a millionth of an inch will do! We bend space, to a minute extent, every time we generate an electric or magnetic field. Perhaps one day we may be able to bend a piece of it at right angles to itself.

If you consider that all this is wild and far-out speculation, with no basis in reality and no observational facts to support it, you are 99 per cent correct. But I am encouraged to take the fourth dimension a little more seriously than I have done for many years because of a recent alarming debacle in nuclear physics, which has left everyone in a very thoughtful mood. It involves one of the most fundamental but disregarded concepts of everyday life – the difference between right and left.

Let us return to Flatland for a moment. Imagine a rectangle in that two-dimensional world, and assume that it is cut into halves by being divided along a diagonal. (I suggest that you tear a sheet of paper in two to follow this demonstration. Note that it must be a rectangular sheet, with unequal sides – *not* a square.)

Now the two triangular halves of the divided rectangle are identical in every respect. We can prove this by placing one on top of the other and noting that the upper one exactly covers the lower. The Flatlanders, of course, cannot perform this experiment, from the nature of their universe, but they can do something that is equivalent. They can put marks against the three corners of one triangle, push it out of the way, and show that its twin will occupy the same space. In all respects, therefore, the triangles are equal; or as Euclid would say, congruent.

(What has all this to do with walking through walls and collecting souvenirs from the vaults of Fort Knox? Patience, please; there is no easy road to success, even *via* the Fourth Dimension.)

At this point we will give the Flatlanders something to think about. We will pick up one of the triangles, flip it over, and put it back in Flatland.

You will appreciate at once that something rather odd has happened. Though they are still the same size, *the two triangles are no longer equal.* They are now mirror images – one right-handed, one left-handed. No amount of pushing and manœuvring by the Flatlanders can make them occupy identical spaces. They differ from each other like a pair of boots or gloves, or screws of opposite pitch.

Confronted by the miracle of a body being turned into its mirror image, a sufficiently intelligent Flatlander might deduce the only possible explanation – that the object had been 'rotated' through a space at right-angles to his own universe, the mythical Third Dimension. In exactly the same manner, if we ever encounter cases of solid bodies being converted into their images, it will be a proof that a Fourth Dimension exists.*

Something quite as bad as this has just happened in nuclear physics, and the theoreticians are still reeling from the shock. In 1957 one of the long-standing 'laws' of physics was overthrown – the Principle of Parity. This states, in effect, that there is no real distinction between left and right – one is just as good as the other as far as Nature is concerned. For decades the principle had been regarded as self-evident, because any other assumption seemed absurd.

Well, we have now discovered that in some nuclear reactions Nature is left-handed, while in others she is right-handed. This offends all our ideas of symmetry and the fitness of things, and it seems to me (though I am rushing in where angels with Master's degrees in quantum mechanics might fear to tread) that one way of saving the situation is by invoking the Fourth Dimension. For then right-handedness and left-handedness will no longer bother us, because they will be identical. In a Four Dimensional universe the distinction vanishes, and so, accordingly, does the paradox now worrying the physicists. The Nobel Prize committee can contact me through my publishers.

In case anyone feels that four-dimensional effects on the nuclear scale, even if they exist, will be too small to be of practical use, may I remind him that a short while ago uranium fission concerned only a handful of atoms, not the entire human race. The principle is all that matters; the problem of size, we can deal with later.

I must admit that, when I started on the quest for invisibility a few thousand words back, I had no idea that it would lead into the Fourth Dimension. But that is typical of science; the direct and obvious approach is often the wrong one – the programme aimed at one objective reaches a wholly different target. For centuries the alchemists mixed endless potions in their search for gold; they never found it, but they created chemistry. The transmutation of the elements lay, not through the retort and the crucible, but along a road which began in the glowing plasma of a vacuum tube. And it led to metals more precious, and even more deadly, than gold.

Invisibility, the interpenetration of matter, the Fourth Dimension – these are the dreams and fantasies of science, and the probability is overwhelming that they will always remain so. But stranger things have happened in the past, and are happening now. As I write these words, this room and my body are sleeted by a myriad particles which I can neither see nor sense; some of them are sweeping upwards like a silent gale through the solid core of Earth itself. Before such marvels, incredulity is chastened; and it would be wise to be sceptical even of scepticism.

FIFTEEN

THE ROAD TO LILLIPUT

When the micropscope was invented at the beginning of the seventeenth century, it revealed an entire new order of creation to Mankind. Below the range of the visible was an unsuspected universe of living creatures, dwindling down, down, down to unimaginable minuteness. This discovery, coming at the same time as the telescope's revelations at the opposite end of the scale, set men thinking about the question of size.

One of the earliest – and certainly the most famous – results of that thinking was *Gulliver's Travels.* The genius of Swift (inspired by his own amateur observations; he bought a microscope for Stella) seized upon the change of perspective caused by magnification as a means of satire, and both Lilliput and Brobdingnag have now passed into our language. As also, though invariably misquoted, has Swift's stanza on the same theme:

So, naturalists observe, a flea
Has smaller fleas that on him prey;
And these have smaller still to bite 'em,
And so proceed *ad infinitum.*

Although it was quickly discovered, to the general relief, that Swift's Brobdingnag existed nowhere on Earth, the rather more attractive idea of minute or even microscopic races of men continued to fascinate writers. (It is more attractive, of course, because we are all scared of giants, whereas we feel that we could cope with midgets. In reality, it would be just the reverse.) The classic story of the micro-world is Fitz-James O'Brien's *The Diamond Lens,* published in 1858, when the author was still in his twenties, with only four years of life ahead of him before his brilliant career would be cut short by the Civil War. *The Diamond Lens* describes what is perhaps the most frustrating romance in literature; it is the tragedy of a microscopist who falls in love with a woman too small to be visible to the naked eye, and who lives in the world of a water-drop.

Later writers did not let such an obstacle as mere size stand in the way of the plot; they invented drugs which contracted or expanded their characters as desired. The immortal Alice was perhaps the first to taste one of these potions, not yet listed in the Pharmacopoeia; and nowhere else have the difficulties they could cause been so vividly described.

The idea of the micro-, and indeed sub-micro-, world received a fresh lease of life in the 1920s, when the work of Rutherford and others laid bare the nuclear nature of the atom. The thought expressed in Swift's stanza was revived on a far more breathtaking scale. Every atom might be a miniature solar system, with electrons playing the role of inhabited planets – and, conversely, our solar system might be merely an atom in a super-universe.

This theme was taken up with enthusiasm by the prolific science-fiction writer, Ray Cummings, who had a training that many of his colleagues might have envied – he was Edison's secretary for five years. In *The Girl in the Golden Atom* (1919) and later stories, Cummings shrank a whole series of heroes down to sub-electronic size, passing somewhat glibly over such problems as the navigation of internuclear space and the location of the right atom (and the right girl) among the several million million million million different atoms that exist in a few ounces of gold.

Some years ago Hollywood surprised many of us by making a remarkably good movie on the theme of smallness: I refer to *The Incredible Shrinking Man,* which 90 per cent of intelligent film-goers probably judged by its unfortunate title and decided to miss. The most incredible thing about the Shrinking Man (and I imagine that we can thank the author and script-writer Richard Matheson for this) was the fact that he was so *credible,* and the avoidance of the conventional happy ending left his final fate both moving and strangely inspiring. But perhaps I am too easily satisfied; it is so rare to meet a glimmer of intelligence in what film-producers are pleased to call science-fiction movies that one's gratitude tends to overflow.

These stories of miniature and micro-worlds raise two distinct questions: could such worlds exist (not necessarily on our planet), and if so, could we observe or enter them?

As far as the first question is concerned, I think we can give a definite answer, based upon laws familiar to all engineers and biologists, but not to those journalists who love to trot out such ancient fallacies as: 'If an ant were as big as a man, it could carry a load of ten tons.' In fact, it couldn't carry itself.

At any level of size, certain things are possible and others are impossible. The whole world of living creatures with all its wonderful richness and variety, is dominated and controlled by the elementary fact of geometry which states: if you double the size of an object you multiply its area four times – but its volume (and hence weight) eight times. From this mathematical platitude, the most momentous consequences flow. It implies, for instance, that a mouse cannot be as big as an elephant, or an elephant as small as a mouse – and that a man cannot be the size of either.

Let us consider the case of Man. He is already a giant – one of the very largest of the animals. This thought comes as something of a surprise to most people, who forget that the animals larger than man could have their names written on a single sheet of paper, while those that are smaller would fill volume after volume.

Homo sapiens shows a considerable range in size, though the extremes are very rare. The tallest man who has ever lived was perhaps five times the height of the smallest, but you would have to search through millions of cases to find a ratio of four to one – unless you happened to hit on a circus exhibiting both an eight-foot giant and a two-foot midget. And if you did, you would probably find that both were sick and unhappy people, with little chance of reaching the normal span of life.

For the human body is a piece of architecture that has evolved to give its best performance when it is five or six feet tall. Double its height, and it would weigh eight times as much but the bones which supported it would be increased in area of cross-section only four times. The stresses acting upon them would therefore be doubled in intensity; a twelve-foot giant is possible, but he would always be breaking his bones, and would have to be very careful how he moved. To make a twelve-foot version of *Homo sapiens* practical would involve a major redesign, not a straight scaling up. The legs would have to be proportionally much thicker, as the example of the elephant proves. The horse and the elephant both follow the same basic quadripedal design – but compare the relative thickness of their legs! The elephant must be near the sensible limit of size for a land animal; this was reached (if not exceeded) by the forty-ton brontosaurus and that largest of all mammals, the incredible rhinoceros *Baluchitherium,* which stood eighteen feet high at the shoulder. (The head of a giraffe is only sixteen feet from the ground!)

Beyond this size, no structure of flesh and bone could support itself against gravity; if real giants exist anywhere in the universe, their bones will have to be made of metal, which would involve some difficult problems in biochemistry. Or they will have to live on worlds of low-gravity – possibly in space itself, where weight ceases to exist. One of the most interesting – questions in extra-terrestrial zoology is whether life can adapt itself to space by purely evolutionary processes. Almost all biologists would say, ‘Certainly not!’ but I think it unwise to sell Nature short at the present state of our ignorance.

In the direction of smallness, the problems that arise are not quite so obvious, but they are equally fundamental. At first sight there seems no very good reason why a man one foot high need not be a working proposition. There are plenty of mammals this size, based upon the same general design; some of the smaller monkeys, for example, are very much like little men.

Closer examination, however, reveals that their proportions are quite different, their limbs much more slender than man's. For just as a man enlarged to a height of twenty feet would be impractically fragile and underpowered for his weight, so, conversely, one diminished to a height of a foot would be hopelessly clumsy and over-muscled. Small animals need *much* smaller limbs, as is dramatically shown by the insects with their often unbelievably delicate legs and wings. By the time the Incredible Shrinking Man started to measure his height in inches, his grossly overpowered muscles would have torn him to pieces.

But long before then, so many other things would have gone wrong that he would be dead from a dozen causes. All the elaborate mechanisms of the body – respiration, blood circulation, temperature control, to mention only the most obvious – would have failed. When he was a tenth of his original size, the ISM would have a thousandth of his starting weight. (We won't enquire where that missing 99.9 per cent has gone; if he still has it, of course, he is fifty times as dense as platinum and has fallen through the floor.) Yet the area of his lung surfaces, stomach walls, vein and artery cross-sections, has diminished not by a thousand but only by a hundred. His entire metabolism would proceed at ten times the previous rate per unit of his mass; he would probably die of heat-stroke through overproduction of energy.

This sort of argument can be followed to the same *reductio ad absurdum* conclusion for every one of the body's functions, and make it perfectly clear that even if the means existed for expanding or contracting a man, he would be incapacitated and then killed by quite a modest change of scale.* There is no chance that any man will ever be able to stalk warrior-ants through the jungles of the grass, still less marry a Princess in a Golden Atom.

Having made this point, I would like to add one slight reservation. A very good case can be made to the effect that Man is now considerably larger than he need be. Physical strength and the size that necessarily goes with it will be needed less and less in the future. Indeed, size will be a handicap – especially in the cramped quarters of space vehicles – and it has been half-seriously suggested that one way of alleviating the coming shortages of food and raw materials is to breed smaller people. Even a 10 per cent reduction in the average height of the human race would have a very considerable effect, for smaller people would need smaller homes, cars, furniture, clothes – all the way along the line.

There would be no midgets, of course, if *everyone* was three feet high, and the world could then quite comfortably support twice its present population. Few futures, however, seem less likely than this, for thanks to better food and medical care men are growing rather than shrinking. (Harvard graduates, admittedly a privileged class, have been gaining an inch a generation – an astonishing rate which suggests that they will be in real trouble around the year 3,000.) Only a ruthless and all-powerful world dictatorship could reverse this trend; dictators are always small people and one can imagine some future Hitler or Mussolini who determined to assuage his inferiority complex by making his subjects even smaller than he was – though he could hardly expect to see any noticeable results in his own lifetime.

Although small living creatures cannot be manlike, and no man could continue to function if drastically reduced in size, this does not rule out the possibility that extremely small yet intelligent beings might exist if they were constructed upon non-human lines. By altering her designs Nature can circumvent, to a quite remarkable degree, the limitations imposed by changes of scale. Consider, for example, the difference between the albatross and the tiniest midge, barely visible to the eye. Both are aerial creatures that fly by flapping their wings – and there the resemblance ceases. Anyone knowing only the midge could make a very convincing case for the impossibility of the albatross – and vice versa. Yet both exist, and both fly, though one weighs a billion times as much as the other. They represent the extreme ends of the evolutionary spectrum, when the resources of biological materials and mechanisms have been stretched to the limit. No bird much larger than an albatross could fly; as is demonstrated by the ostrich, the moa and their giant ancestors, as terrifying as dinosaurs. No insect much smaller than a midge could have any control of its movements through the air; though it might float as helplessly as the planktonic creatures drift through the sea, it could not fly.

Even a complete redesign, therefore, permits only a limited, and not an indefinite reduction in size. Sooner or later we come up against the fact that the basic structural elements of living creatures – the building blocks of life – cannot be made much smaller than they already are. All animals are constructed of cells, and all cells are of much the same size. Those from an elephant are only twice the size of those from a mouse.

It is as if all living creatures are like houses, built from bricks which vary only slightly in size. It follows, therefore, that very small animals must also be very simple animals, because they can contain only a limited number of components. You cannot build a doll’s house out of full-sized bricks.

Intelligence, whatever else it may be, is at least partly a byproduct of cellular complexity. Small brains cannot be as complex as large brains, because they must contain fewer cells. One can imagine the human brain still functioning well at half its present size – but not at one-tenth. If, on planets with powerful gravitational fields, living creatures are reduced to a height of a few inches, they cannot be intelligent – unless they make up for their lost height by increasing their area, to give an adequate volume of brain. There might be doll-like animals on 50-g worlds, but anything capable of rational thought would look not like a manikin, but a pancake.

Not only intelligence but life itself becomes impossible as we continue down the scale of size. Only just beyond the limit of today's microscopes, the essential granularity of Nature makes its appearance. As the cell is the basic building block of *all* living creatures, so atoms and molecules are the building blocks of the cell. Some minute bacteria are only a few score molecules on a side; the viruses, which mark the frontier between life and non-life, are even smaller. But no house can be smaller than a single brick, and nothing that lives can be smaller than a single protein molecule, which is the chemical basis of life. The largest proteins are about a millionth of a centimetre long; that is a nice round figure to remember, as the last milestone on the road down from the world of life.

Although it is conceivable that more efficient types of organism may have evolved on other planets (indeed, it is somewhat immodest to assume otherwise) is seems very unlikely that they could be *so* much more efficient that they could alter those conclusions. We can dismiss, therefore, those ingenious stories of midget (or even microscopic) spaceships as pure fantasy. If you are ever persistently buzzed by a strange metallic object that looks like a beetle, it will be a beetle.

There is not much that can or need be said about theories of the sub-universe, and the suggestion that atoms may be miniature solar systems. Stories based on this theme are now virtually extinct; they were killed when it was discovered that electrons behaved in most unplanetary fashions, being waves at one moment and particles the next. The cosy and easily pictured. Rutherford-Bohr atom lasted only a few years – and even in that model, electrons were assumed to jump instantaneously from orbit to orbit, which would have been very unsettling to their inhabitants. Wave mechanics, the Uncertainty Principle, and the detection of such puzzling particles as mesons and neutrinos made it very clear that atoms were nothing like solar systems, or indeed anything that the mind of men had ever envisaged before.

I might mention, with a slight shudder, that in *Amazing Stories* during 1932-5 one J. W. Skidmore produced an entire series of tales about a sub-atomic romance between an electron, Nega and a proton, Posi. How any author could have spun this horrid whimsey out over five stories (or even one) I cannot now imagine; his success may be judged from the fact that though I read the entire Posi and Nega series at the time of publication, I cannot for the life of me remember whether boy eventually met girl, and, if so, what happened. The matter is beginning to prey on my mind, but as I am 10,000 miles from the Library of Congress there is nothing I can do about it.

Almost invariably, stories of microcosmic universes ignored the fact that a change of size always involves a corresponding change of time-rate. Small creatures live short, active lives; to birds and flies, we must be a very slow-moving, sluggish creatures. If we go to the limiting case of the atom and suppose that the orbiting electrons were in fact worlds in their own right, they must have fantastically short 'years'. In the Rutherford-Bohr model of the hydrogen atom, the single orbital electron makes about a million million revolutions round the nucleus every *second.* If this corresponds to the 88-day year of Mercury, the innermost planet in our solar system, it would mean that time in the hydrogen atom must pass about 10 thousand million million million times more swiftly than it does in our macroscopic universe.

No science-fiction hero, therefore, could ever make two visits to the same sub-atomic world. If he stepped back into his own universe for a single hour, and then returned to the atom, he would find that hundreds of billions of years had passed. And, conversely, any round trip to the micro-world would have to be practically instantaneous in our time, otherwise the traveller would die of old age among the atoms. I do recall one story in which a scientist sent his daughter and his assistant on a brief visit to the sub-atomic universe and was disconcerted to welcome back several hundred of their great-great-great-great-grandchildren a couple of minutes later; even so, I fear that the author, though he was on the right' lines, grossly under-estimated the magnitude of the problem. It would not be question of a few human generations – but the lifetime of many suns.

For Time can be a barrier more unyielding than Space; this will be particularly true if we ever discover, and attempt to communicate with, extremely large intelligent entities. A number of writers have explored this idea, which does not conflict with my earlier remarks about the impossibility of giants. I was speaking then of *planetary* environments – and there may be creatures larger than planets.

One writer to handle this theme was Fred Hoyle – and whatever views one may take of Professor Hoyle's cosmology, nobody doubts that he knows his physics. In *The Black Cloud* he described, with great plausibility and conviction, a gaseous invader from interstellar space, some 100 million miles in diameter – in fact, a kind of intelligent comet.

Even if the 'thoughts' of such a creature were propagated by radio waves, as Hoyle suggested, it would take ten minutes for a single impulse to travel from one end of it to the other. A nerve impulse can make the trip across the human brain in a few thousandths of a second, so mental operations involving the whole of the Black Cloud would take perhaps a million times longer than those of a human mind. We would get very tired waiting for its answers; a short sentence would take a couple of months to deliver.

However, the Black Cloud might be able to talk to us at our own rate, or even at the rate of our fastest teleprinters, by detailing a minute and localized fraction of itself to deal with so trivial a problem. In that case, we could hardly claim to be in communication with It as a whole, any more than an ant could claim to have made contact with a man, because his toe twitched when it walked across his foot.

These are rather humbling thoughts, but I do not think that they are necessarily fantastic. Looking down towards the atom, we can see, a few orders of magnitude beneath us, first the end of intelligence, then the end of life. There is no such finality in the other direction, and as yet we have no inkling of our position in the hierarchy of the Universe. There may be intellects among the stars as vast as worlds, or suns … or solar systems. Indeed, the whole galaxy, as Olaf Stapledon suggested long ago, may be evolving towards consciousness, if it has not already done so. It contains, after all, ten times as many suns as there are cells in a human brain …

The road to Lilliput is short, and it leads nowhere. But the road to Brobdingnag is another matter; we can see along it only a little way, as it winds outwards through the stars, and we cannot guess what strange travellers it carries. It may be well for our peace of mind if we never know.

SIXTEEN

VOICES FROM THE SKY[*]

In the closing days of 1958, a human voice spoke for the first time from space. It was the President of the United States, broadcasting a Christmas message to the world. Yet that friendly greeting from an orbiting Atlas satellite, leaping across all barriers of geography and nationality, was as fateful a sound as any in the history of mankind. It marked the dawn of a new age of communication, which will transform the cultural, political, economic and even linguistic patterns of our world.

It is simple enough to demonstrate this logically – as I hope to do – but very difficult to grasp its full meaning. So wonderful are today's techniques of communication, so integrated into the very fabric of our society, that we overlook their gross limitations, and find it hard to imagine any substantial improvements. We are like the early Victorians who saw no value in the electric telegraph; semaphores or flashing lights had always been good enough for those hustlers who wanted something faster than the mail-coach …

We may laugh at this attitude; yet we are still, for all our ability to pluck sound and vision from the empty air, scarcely out of the Morse-buzzer age. Within a few years, communications satellites beyond the atmosphere will make our present facilities seem as primitive as Indian smoke signals, and we as blind and deaf as our grandparents before the coming of the electron tube.

All these revolutionary consequences stem from a fact so simple and so obvious that one almost hesitates to mention it. The radio waves which are now our chief message-bearers travel in straight lines, like light itself. But the world, unfortunately, is round.

Only the curious accident that the Earth is surrounded by a reflecting layer – the ionosphere – makes long-distance radio possible. This invisible mirror in the sky reflects back waves in the broadcast and short-wave bands, but its performance is somewhat erratic and it does not function at all on the *very* short waves. These slice straight through it and head on out into space, and thus cannot be used for long distance communication. (Long-distance, that is, by terrestrial standards. They serve admirably for talking to planets and spaceships.)

It is the television engineer who is most badly affected by this state of affairs. For technical reasons, TV is confined to the very short waves – precisely those which are not reflected back to Earth. TV programmes go straight on out into space; they may be picked up beautifully on the Moon, but not in the next country.

This is the reason why hundreds of TV stations are needed to cover a large area like Europe or the United States. Still more serious, it is impossible to span the oceans; they remain as great an obstacle to TV as they were to the human voice before the invention of radio itself. To exchange TV programmes between Europe and America would require a kind of electronic bucket-chain of perhaps fifty ships moored in a line across the Atlantic, relaying the signals from one to the other. This is not, to say the least, a very practical solution.

There is a simpler answer. Just *one* relay station will do the job – if it is in a satellite a few thousand miles above the Earth. All that would be required would be a receiver to pick up the signals from one continent, and a transmitter to rebroadcast them to the other.

But transatlantic TV is only a modest beginning. If the relay satellite were far enough out – say 10,000 miles – its broadcasts would blanket half the world. And two or three such satellites, equally spaced around our planet, could provide TV coverage from Pole to Pole. The clear, clean signals coming directly down from the sky, with no background interference, and no ghostly echoes picked up by reflexion from nearby buildings, would permit far higher standards of picture quality than those we tolerate today.

Perhaps at this point I may be permitted what has been called the modest cough of the minor poet. To the best of my knowledge, the use of artificial satellites to provide global TV was first proposed by myself in the October 1945 issue of the British radio journal *Wireless World*. The scheme then put forward, under the snappy title ‘Extra-terrestrial Relays’, envisaged the use of three satellites 22,000 miles above the Equator. At this particular height, a satellite takes exactly 24 hours to complete one orbit, and thus stays fixed for ever over the same spot on the Earth. The laws of celestial mechanics can thus provide us with the equivalent of invisible TV towers 22,000 miles high. Even as I write these words, preparations are being made by the Hughes Aircraft Company and the U.S. Army to launch communications satellites into this 24-hour orbit.

At first sight, global TV may hardly seem a revolutionary force capable of transforming our civilisation. Let us, therefore, look at some of its consequences in more detail.

In a few years, every large nation will be able to establish (or rent) its own space-borne radio and TV transmitters, able to broadcast really high-quality programmes to the entire planet. There will be no shortage of wave-lengths – as there is today even for local services. One of the incidental advantages of satellite relays is that they will make available vast new bands of the radio spectrum, providing ‘ether space’ for at least a million simultaneous TV channels, or a *billion* radio circuits!

This will mean the end of all distance barriers to sound and vision alike. New Yorkers or Londoners will be able to tune in to Moscow or Peking as easily as to their local station. And, of course, vice versa.

Think what this will mean. Until today, even radio has been parochial, except to the short-wave fan willing to put up with the fades and crackles and banshee wailings of the ionosphere. Yet now the great highway of the ether will be thrown open to the whole world, and all men will become neighbours – whether they like it or not. Any form of censorship, political or otherwise, would be impossible; to jam signals coming down from the heavens is almost as difficult as blocking the light of the stars. The Russians could do nothing to stop their people seeing the American way of life; on the other hand, Madison Avenue agencies and Watch Committees might be equally distressed – though for different reasons – at a nationwide switch to uninhibited telecasts from Montmartre …

Such freedom of communication will have an ultimately overwhelming effect on the cultural, political and moral climate of our planet. It holds danger as well as promise. If you doubt this, consider the following quite unimaginative extrapolation, which might be entitled ‘How to conquer the world without anyone noticing’.

By 1970 the USSR had established the first high-powered satellite TV relay above Asia, broadcasting in several languages so that more than a billion human beings can understand the programmes. At the same time, in a well-organised sales campaign spearheaded by demonstrations, Russian trade missions have been flooding the East with cheap, transistorised battery-powered receivers. There is scarcely a village which cannot afford one and it doesn’t cost the USSR a thing; it even makes a small profit on the deal …

And so millions who have never learned to read, who have never seen a movie, who have no rival distractions, fall under the hypnotic spell which even ostensibly educated nations have been unable to resist. Good entertainment, rapid (if slanted) news reporting, Russian language lessons, instructional programmes of a ‘Do It Yourself’ type useful to backward communities, quiz programmes in which the first prizes are usually trips to the Soviet Union – it takes little imagination to see the pattern. In a few years of skilful propaganda, the uncommitted nations would be committed.[*]

It may be no exaggeration to say that priority in establishing the satellite communication system may determine whether, fifty years from now, Russian or English is the main language of mankind. The TV satellite is mightier than the ICBM, and intercontinental TV may indeed be the ultimate weapon.

But let us turn aside from the political aspects of the TV satellites and look in more detail at their domestic effects. One of these will be all to the good: we may see the end of the hideous antenna arrays that have ruined the skylines of all our cities and made a mockery of architecture for the last decade. The antennae of the future will be small, neat saucers or lens systems like the now familiar radio-telescopes. As they will lie on their backs pointing up at the sky they can be tucked into roofs and attics – and they will need no tottering towers to support them high in the air. This aesthetic dividend, though small, should not be despised.

Many will look forward, with a certain malevolent glee, to the effects of outside competition upon commercial programmes. At least 100,000,000 underprivileged Americans have never known the joys of hucksterless radio or TV; they are like readers who have become reconciled to the fact that the fifth page of every book consists of advertisements *which they are not allowed to skip*. If the Russians are clever enough to take advantage of their opportunity, they can gain an enormous audience merely by omitting the soap and laxative announcements.

The advent of global TV and radio coverage will end, for better or worse, the cultural and political isolation which still exists over the whole world, outside the great cities. As one who has travelled widely throughout the United States, I have long been appalled by the intellectual vacuum into which you are plunged as soon as you get out of range of New York, San Francisco, Boston, Chicago and a handful of other oases. This applies both to newspapers and to radio/TV; how often have I spent fruitless hours at places like Skunksville, Ugh., searching for a copy of the *New York Times* so that I could find out what was happening to the planet Earth. And as far as the ether waves are concerned, there are few more harrowing experiences than a sweep across the radio bands in the Deep South, especially on a Sunday morning. In England, at least, one is never far from civilization (ie the BBC's Third Programme).

The abolition of all barriers to free intellectual and cultural intercourse will complete the revolution started by the automobile half a century ago and timidly continued by today's short-ranged electronics. It will mean the eventual end of the limited, small-town mentality which, it is true, has a certain charm (especially to nostalgic novelists, and especially from a distance). When all men, wherever they may be, have equal access to the same vast communications network, they will inevitably become Citizens of the World, and a major problem of the future will be the preservation of regional characteristics of value and interest. There is grave danger of global levelling-down; the troughs in Man's cultural heritage must not be filled at the price of demolishing the peaks.

The universal communication system will have a profound impact upon language. As already suggested, it may lead to a single dominant tongue, others becoming merely local dialects. More probably it will result in a bi- or tri-lingual planet; in this respect, Switzerland may be the prototype of tomorrow's world. Far higher above the Earth than the builders of Babel ever aspired we may at last undo the curse that was visited upon them.

All that has been described so far – even this last development – will result from the application of existing techniques, merely made world-wide by the use of satellite relays. It is time now to consider some of the wholly new services which will become feasible, if we wish to exploit them.

The most obvious is the personal transceiver, so small and compact that every man carries one with no more inconvenience than a wristwatch. This, of course, is an old dream, and anyone who doubts that it can be realized is simply unaware of current achievements in electronics. Radio receivers have now been built which make the most compact transistor portables look like 1925 cabinet models. The smallest so far revealed by the microminiaturization experts is about the size of a lump of sugar.

Without going into technical details (of interest largely to those who can already think of the answers) the time will come when we will be able to call a person anywhere on Earth, merely by dialling a number. He will be located automatically, whether he is in mid-ocean, in the heart of a great city, or crossing the Sahara. This device alone may change the patterns of society and commerce as greatly as the telephone, its primitive ancestor, has already done.

Its perils and disadvantages are obvious; there are no wholly beneficial inventions. Yet think of the countless lives it would save, the tragedies and heartbreaks it would avert. (Remember what the telephone has meant to lonely people everywhere.)

No one need ever again be lost, for a simple position- and direction-finding device could be incorporated in the receiver, based on the principle of today's radar navigational aids. And in case of danger or accident, help could be summoned merely by pressing an 'Emergency' button.

If you think that this will make the world a claustrophobically small place, in which you can never escape from friends or family, or even run any stimulating risks, you are quite correct. But you need not worry; there is more than enough of danger and distance in the bottomless chasm of Space. Earth is home now; let us make it cosy and comfortable and safe. The pioneers will be elsewhere.

As communications improve, so the need for transportation will decrease. Our grandchildren will scarcely believe that millions once spent hours of every day fighting their way into city offices – where, as often as not, they did nothing that could not have been achieved over telecommunication links.

For global phone and vision services, enabling men to confer with each other anywhere on the planet, are only a beginning. Even now we have data-handling systems linking together factories and offices miles apart, controlling nation-wide industrial empires. Electronics is already permitting the decentralization which rising rents and transport costs – not to mention the threat of the mushroom cloud – encourage more strongly every year.

The business of the future may be run by executives who are scarcely ever in each other's physical presence. It will not even have an address or a central office – only the equivalent of a telephone number. For its files and records will be space rented in the memory units of computers that could be located anywhere on Earth: the information stored in them could be read off on high-speed printers whenever any of the firm's officers needed it.

The time may come when half the world's business will be transacted through vast memory banks beneath the Arizona desert, the Mongolian Steppes, the Labrador muskeg or wherever land is cheap and useless for any other purpose. For all spots on Earth, of course, would be equally accessible to the beams of the relay satellites: to sweep from Pole to Pole would mean merely turning the directional antennae through seventeen degrees.

And so the captains of industry of the twenty-first century may live where they please, running their affairs through computer keyboards and information-handling machines in their homes. Only on rare occasions would there be any need for more of the personal touch than could be obtained *via* wide-screen full-colour TV. The business lunch of the future could be conducted perfectly well with the two halves of the table 10,000 miles apart; all that would be missing would be the handshakes and exchange of cigars.

Administrative and executive skills are not the only ones which would thus become independent of geography. Distance has already been abolished for the three basic senses of sight, hearing and touch – the latter thanks to the development of remote-handling devices in the atomic energy field. *Any* activity which depends on these senses can, therefore, be carried out over radio circuits. The time will certainly come when surgeons will be able to operate a world away from their patients, and every hospital will be able to call on the services of the best specialists, wherever they may be. We will have more to say in the next two chapters about the linking of human senses into communications networks.

An application of satellites which has already been considered in some detail by the astronautical engineers is what has been called the Orbital Post Office, which will probably make air-mail obsolete in the quite near future. Modern facsimile systems can automatically transmit and reproduce the equivalent of an entire book in less than a minute. By using these techniques, a single satellite could handle the whole of today's transatlantic correspondence.

A few years from now, when you wish to send an urgent message, you will purchase a standard letter-form on which you will write or type whatever you have to say. At the local office the form will be fed into a machine which scans the marks on the paper and converts them into electrical signals. These will be radioed up to the nearest relay satellite, routed in the appropriate direction round the Earth, and picked up at the destination where they are reproduced on a blank form identical with the one you inscribed. The transmission itself would take a fraction of a second; the door-to-door delivery would extend this time to several hours, but eventually letters should never take more than a day between any two points on the Earth. There are, of course, problems of privacy, which might be solved by robot handling at all stages of the operation. However, even the old-style human postmen have been known to read the mail …

Perhaps a decade beyond the Orbital Post Office lies something even more startling – the Orbital Newspaper. This will be made possible by more sophisticated descendants of the reproducing and facsimile machines now found in most up-to-date offices. One of these, working in conjunction with the TV set, will be able on demand to make a permanent record of the picture flashed on the screen. Thus when you want your daily paper, you will switch to the appropriate channel, press the right button – and collect the latest edition as it emerges from the slot. It may be merely a one-page news-sheet; the editorials will be available on another channel – sports, book reviews, drama, advertising, on others. We will select what we need, and ignore the rest, thus saving whole forests for posterity. The Orbital newspaper will have little more than the name in common with the newspaper of today.

Nor will the matter end here. Over the same circuits we will be able to conjure up, from central libraries and information banks, copies of any document we desire from Magna Carta to the current Earth-Moon passenger schedules. Even books may one day be 'distributed' in this manner, though their format will have to be changed drastically to make this possible.

All publishers would do well to contemplate these really staggering prospects. Most affected will be newspapers and pocket-books; practically untouched by the coming revolution will be art volumes and quality magazines, which involve not only fine printing but elaborate manufacturing processes. The dailies may well tremble; the glossy monthlies have little to fear.

How mankind will cope with the avalanche of information and entertainment about to descend upon it from the skies, only the future can show. Once again Science, with its usual cheerful irresponsibility, has left another squalling infant on civilization's doorstep. It may grow up to be as big a problem-child as the one born amid the clicking of Geiger counters beneath the Chicago University squash-court, back in 1942.

For will there be time to do any work at all on a planet saturated from Pole to Pole with fine entertainment, first-class music, brilliant discussions, superbly executed athletics, and every conceivable type of information service? Even now, it is claimed, our children spend a sixth of their waking lives glued to the cathode-ray tube. We are becoming a race of watchers, not of doers. The miraculous powers that are yet to come may well prove more than our self-discipline can withstand.

If this is so, then the epitaph of our race should read, in fleeting, fluorescent letters: 'Whom the Gods would destroy, they first give TV.'

Epilogue

I have deliberately left the preceding chapter unchanged, since as an example of attempted – and partially fulfilled – prediction it would seem to be of some historic interest. The names TELSTAR, COMSAT, and INTELSAT have now entered the consciousness of mankind, and the footnote on page 204 came true with the launching of SYNCOM. By the mid-70s, the first direct-broadcast satellites – whose programmes can be received by ordinary TV sets with a few hundred dollars worth of auxiliary equipment – will be in orbit, and the communications revolution will be upon us.

'To revert to the opening sentence of this chapter; on August 20th, 1971, I was privileged to meet Mrs Mamie Eisenhower at the US State Department, when we were both invited to the ceremonies attending the signing of the 80-nation INTELSAT (International Telecommunications Satellite Organisation) Agreement. My speech at the subsequent luncheon seems a good way of rounding off this chapter:

I submit that the eventual impact of the communications satellite upon the whole human race will be at least as great as that of the telephone upon the so-called developed societies.

In fact, as far as real communications are concerned, there are as yet *no* developed societies; we are all still in the semaphore and smoke-signal stage. And we are now about to witness an interesting situation in which many countries, particularly in Asia and Africa, are going to leapfrog a whole era of communications technology and go straight into the space age. They will never know the vast networks of cables and microwave links that this continent has built at such enormous cost both in money and in natural resources. The satellites can do far more and at far less expense to the environment.

INTELSAT, of course, is concerned primarily with point-to-point communications involving large ground stations. It provides the first reliable, high-quality, wide-band links between all nations that wish to join, and the importance of this cannot be overestimated. Yet it is only a beginning, and I would like to look a little further into the future.

Two years from now, NASA will launch the first satellite, the ATS-F, which will have sufficient power for its signals to be picked up by an ordinary, domestic television set plus about $200 worth of additional equipment. In 1974, this satellite will be stationed over India and, if all goes well, the first experiment in the use of space communications for mass education will begin.

I have just come from India, where I have been making a TV film on ‘The Promise of Space’. In a village outside Delhi, we set up the prototype antenna – a simple, umbrella-shaped, wire-mesh structure about three meters across. Anyone can put it together in a few hours, and only one antenna per village is needed to start a social and economic revolution.

The *engineering* problems of bringing education, literacy, improved hygiene, and agricultural techniques to every human being on this planet have now been solved. The cost would be about a dollar per person, *per year*. The benefits in health, happiness, and wealth would be immeasurable.

But, of course, the technical problem is the easy one. Do we have the imagination and the statesmanship to use this new tool for the benefit of all mankind? Or will it be used merely to peddle detergents and propaganda?

I am an optimist; anyone interested in the future has to be. I believe that communications satellites can unite mankind. Let me remind you that, whatever the history books say, this great country was created a little more than a hundred years ago by two inventions. Without them, the United States was impossible; with them, it was inevitable. Those inventions, of course, were the railroad and the electric telegraph.

Today, we are seeing on a global scale an almost exact parallel to that situation. What the railroads and the telegraph did here a century ago, the jets and the communications satellites are doing now to all the world.

I hope you will remember this analogy in the years ahead. For today, whether you intend it-or not – whether you *wish* it or not – you have signed far more than just another intergovernmental agreement.

You have just signed a first draft of the Articles of Federation of the United States of Earth.

SEVENTEEN

BRAIN AND BODY

The human brain is the most complicated structure in the known Universe – but as practically nothing of the Universe *is* known, it is probably fairly low in the hierarchy of organic computers. Nevertheless, it contains powers and potentialities still largely untapped, and perhaps unguessed-at. It is one of the strangest of all facts, impossible for the sensitive mind to contemplate without melancholy, that for at least 50,000 years there have been men on this planet who could conduct a symphony orchestra, discover theorems in pure mathematics, act as secretaries of the United Nations, or pilot a spaceship – had they been given the chance. Probably 99 per cent of human ability has been wholly wasted; even today, those of us who consider ourselves cultured and educated operate for most of our time as automatic machines, and glimpse the profounder resources of our minds only once or twice in a lifetime.

In the speculations that follow, I shall ignore all paranormal and so-called Psi phenomena. If these exist, and can be controlled, they may dominate the entire future of mental activity, and change the patterns of human culture in manners unpredictable today. But at the present stage of our ignorance, such surmises are profitless and lead all too readily into the quaking quagmires of mysticism. The known powers of the mind are already so astonishing that there is no need to invoke new ones.

Let us first consider Memory. No one has been able to form a reliable estimate of the number of facts or impressions the brain can store during a lifetime. There is considerable evidence that we never forget *anything;* we are just unable to put our hands on it at the moment. We seldom encounter really impressive feats of memory these days, because there is little need for them in our world of books and documents. Before the invention of writing, all history and literature had to be carried in the head and passed on by word of mouth. Even today, there are still men who can recite the whole of the Bible or the Koran, just as once they could recite Homer.

The work of Dr Wilder Penfield and his associates at Montreal has shown, in a dramatic fashion, that long-lost memories can be revived by the electrical stimulation of certain areas of the brain, almost as if a movie record were being played back in the mind. The subject relives, in vivid detail (colour, scent, sound) some past experience – but is aware that it is a memory, and not a present occurrence. Hypnotic techniques can also produce similar effects, a fact which was used to advantage by Freud for the treatment of mental disorders.

When we discover how the brain manages to filter and store the blizzard of impressions pouring into it during every second of our lives, we may gain conscious or artificial control of memory. It would no longer be an inefficient, hit-and-miss process; if you wanted to re-read a page of a newspaper you had seen at a certain moment thirty years go, you could do just that, by stimulation of the proper brain cells. In a sense, this would be a kind of time-travel into the past – perhaps the only kind that will ever be possible. It would be a wonderful power to possess, and – unlike many great powers – would appear to be almost wholly beneficial.

It could revolutionize legal procedures. No one could ever again answer 'I've forgotten' to the classic question, 'What were you doing on the night of the twenty-third?' Witnesses could no longer confuse the issue by accounts of what they *thought* they had seen. Let us hope that memory stimulation would not be compulsory in the law courts, but if anyone pleaded this future version of the Fifth Amendment, the obvious conclusions would be withdrawn.

And how wonderful it would be to go back through one's past, to revive old pleasures and, in the light of later knowledge, mitigate old sorrows and learn from ancient mistakes. It has been said, falsely, that a drowning man's life flashes before his eyes. Yet perhaps one day, in extreme old age, those who no longer have any interest in the future may be given the opportunity of reliving their past, and greeting again those they knew and loved when they were young. Even this, as we shall see later, might be not a preparation for death but the prelude to a new birth.

Perhaps even more important than the stimulation of old memories would be its inverse – the creation of new ones. It is hard to think of any invention that would be more valuable than the device which science-fiction writers have called a Mechanical Educator. As depicted by authors and artists, this remarkable gadget usually resembles the permanent-wave machine at a ladies' hair-dressers', and it performs a rather similar function – though on the material *inside* the skull. It is not to be confused with the teaching machines now coming into widespread use, though one day these may be recognized as its remote ancestors.

The Mechanical Educator could impress on the brain, in a matter of a few minutes, knowledge and skills which might otherwise take a lifetime to acquire.

A very good analogy is the manufacture of a gramophone record; the music may have taken an hour to perform, but the disc is stamped out in a fraction of a second, and the plastic ‘remembers’ the performance perfectly. This would have appeared impossible, even in theory, to the most imaginative of scientists only a century ago.

Impressing information directly on to the brain, so that we can know things without ever learning them, seems equally impossible today; it must certainly remain out of the question until our understanding of mental processes has advanced immeasurably. Yet the Mechanical Educator – or some technique which performs similar functions – is such an urgent need that civilization cannot continue for any more decades without it. The knowledge in the world is doubling every ten years – and the rate is itself increasing. Already, twenty years of schooling are insufficient; soon we will have died of old age before we have learned how to live, and our entire culture will have collapsed owing to its incomprehensible complexity.

In the past, whenever a need has arisen, it has always been filled with some promptitude. For this reason, though I have no idea how it would really operate, and suggest that it may be a complex of techniques rather than a piece of mechanical hardware, I feel fairly convinced that the Mechanical Educator will be invented. If it is not, then the line of evolution discussed in the next chapter will soon be predominant, and the end of human culture is already in sight.

There are many other possibilities, and some certainties, involving the direct manipulation of the brain. It has already been demonstrated that the behaviour of animals – and men – can be profoundly modified if minute electrical impulses are fed into certain regions of the cerebral cortex. Personality can be completely altered, so that a cat will become terrified at the mere sight of a mouse, and a vicious monkey will become friendly and cooperative.

Perhaps the most sensational results of this experimentation, which may be fraught with more social consequences than the early work of the nuclear physicists, is the discovery of the so-called pleasure or rewarding centres in the brain. Animals with electrodes implanted in these areas quickly learn to operate the switch controlling the immensely enjoyable electrical stimulus, and develop such an addiction that nothing else interests them. Monkeys have been known to press the reward button three times a second for eighteen hours on end, completely undistracted either by food or sex. There are also pain or punishment areas of the brain; an animal will work with equal single-mindedness to switch *off* any current fed into these.

The possibilities here, for good and evil, are so obvious that there is no point in exaggerating or discounting them. Electronic possession of human robots controlled from a central broadcasting station is something that even George Orwell never thought of; but it may be technically possible long before 1984.

One of the many bizarre facts revealed by hypnosis is that false, but absolutely convincing, memories can be fed to a subject, who will later be prepared to swear that these things really happened to him. We have all experienced dreams so vivid that, on awaking, we confuse them with reality; for twenty years I have been haunted by the ‘memory’ of a spectacular Spitfire crash which I have never been able to classify as a real event or an hallucination.

Artificial memories, if they could be composed, taped and then fed into the brain by electrical or other means, would be a form of vicarious experience, far more vivid (because affecting all the senses) than anything that could be produced by the massed resources of Hollywood. They would, indeed, be the ultimate form of entertainment – a fictitious experience more real than reality. It has been questioned whether most people would want to live waking lives all, if dream factories could fulfil every desire at the cost of a few pence-worth of electricity.

We should never forget that all our knowledge of the world around us comes through a very limited number of senses, of which sight and hearing are the most important. When these sense-channels are by-passed, or their normal inputs interfered with, we experience illusions which have no external reality. One of the simplest ways of proving this is to sit for some time in a completely darkened room, and then to gently pinch your eyelids with your fingers. You will ‘see’ the most fascinating shapes and colours, yet there is no light acting on the retina. The optic nerves have been fooled by pressure; if we knew the electro-chemical coding whereby images are converted into sensations, we could give sight to men who have no eyes. For the much simpler, though still extremely complex, sense of hearing, something like this has already been done on an experimental basis. The electrical pulses from microphones have been fed, after suitable processing, directly into the auditory nerves of deaf men, who have then been able to experience sound. I use the word ‘experience’ rather than ‘hear’, for we still have a long way to go before we can imitate the signalling system used by the ear; and that employed by the eye is vastly more complicated.

This is a good point to mention a somewhat eerie experiment once carried out by the great physiologist Lord Adrian. Going one better than the witches in *Macbeth,* he took the eye of a toad and connected it to an amplifier and loudspeaker. As he moved about the laboratory, the dead eye imaged him on its retina, and the changing pattern of light and shade was converted into a series of audible clicks. The scientist was, in a crude way, using his sense of hearing to see through the eye of an animal.

One can imagine almost unlimited extensions of this experiment. In principle, the sense impressions from any other living creature – animal or human – might be wired directly into the appropriate sections of the brain. And so one could look through another man's eyes, and even gain some idea of what it must be like to inhabit a non-human body.

We assume that our familiar senses give us a complete picture of our environment, but nothing could be further from the truth. We are stone-deaf and colour blind in a universe of impressions beyond the range of our senses. The world of a dog is a world of scent; that of a dolphin, a symphony of ultrasonic pulses as meaningful as sight. To the bee, on a cloudy day, the diffuse sunlight carries a direction-sign utterly beyond our powers of discrimination, for it can detect the plane vibration of the light-waves. The rattlesnake strikes in total darkness towards the infra-red glow of its living prey – as our guided missiles have learned to do, only in the last few years. There are blind fish in muddy rivers who probe their opaque universe with electric fields, the natural prototype of radar; and all fish have a curious organ, the lateral line, running along their bodies to detect vibrations and pressure changes in the water around them.

Could we interpret such sense impressions, even if they were fed into our brains? Undoubtedly yes, but only after a great deal of training. We have to learn to use all our *own* senses; a new-born baby cannot see, nor can a man whose sight is suddenly restored to him – though the visual mechanism in both cases may be functioning perfectly. The mind behind the brain must first analyse and classify the impulses reaching it, comparing them with other information from the external world – until it all builds up to a consistent picture. Not until then do we 'see'; such integration should also be possible with other sense organs, though we will have to invent new verbs for the experience.

The pilot of an aircraft, gathering data from his scores of dials and gauges, is performing a similar feat. He identifies himself with his vehicle, intellectually and perhaps even emotionally. One day, through telemetering devices, we may be able to do the same with an animal. At last we will know the way of an eagle in the sky, of a whale in the sea, or a tiger in the jungle. And so we will regain our kinship with the animal world, the loss of which is one of modern man's most grievous deprivations.

To return to more down-to-earth concepts, there is no doubt that the range and delicacy of our own senses can be greatly extended by fairly simple means such as training or drugs. Anyone who has watched a blind man reading Braille, or locating objects by sound, will agree without hesitation. (I once saw a blind referee umpiring a table-tennis match – a feat I would not have believed possible. He had even refereed world championship games!) Though the blind provide the most spectacular cases of enhanced sensitivity, there are many other examples. Tea-tasters, vintners, perfumers, deaf lip-readers, come to mind at once: so do those stage ‘clairvoyants’ who can locate hidden objects by detecting intention tremors and other almost imperceptible movements on the part of their aides.

These feats are the result of intensive training, or compensation for the loss of some other sense. But as is well known (perhaps too well known) such drugs as mescaline and lysergic acid can also produce remarkable exaggerations of sensitivity, making the world appear far more real and vivid than in ordinary life. Even if this impression is wholly subjective – like the conviction of a drunken driver that he is controlling his car with Grand Prix skill – the phenomenon is an extremely interesting one, and may have important practical applications.

A priceless mental power which is certainly attainable, because it has often been achieved, would be personal control over pain. The famous statement that ‘Pain isn’t real’ is, of course, literally true – not that it is any help to most of us when we have the toothache. Most (but not all) pain serves a valuable function by acting as a warning sign, and those rare people who cannot experience it are in continual danger. One would not wish, therefore, to abolish pain, but it would be extremely useful to be able to by-pass it, when it had served its purpose, by pressing a kind of mental over-ride button.

In the East, this is such a commonplace trick that no one is particularly surprised by it. I have seen, and photographed in close-up, men and children walking ankle-deep in white-hot embers. Some were burned, but none felt any pain; they were in a state of hypnosis induced by religious ecstasy.[*]

The recent development of sound analgesia proves that the mysterious West also has some tricks up its sleeve. In this technique, used with success by many dentists, the patient listens to a pair of earphones and has to keep adjusting a volume control so that he can hear music in the presence of background noise. While attending to this task, he is unable to feel any pain; it is as if all his incoming wires are too busy to accept any other messages. Probably this, like the performance of the firewalkers, is a form of self-hypnosis, but *we* can only do it with the aid of machines. Perhaps one day, like the yogas and fakirs, we may not need these mental crutches.

From hypnosis it is a short step to sleep – that mysterious state in which we fritter away a third of our pitiably brief lives. No one has ever been able to prove that sleep is essential, though there is no doubt that we cannot do without it for more than a very few days. It appears to be the result of conditioning, over aeons of time, by the diurnal cycle of light and darkness. Because lack of illumination made it difficult to carry out any activities at night, most animals acquired the habit of sleeping until the sun returned. In much the same way, other animals acquired the habit of sleeping through the winter; but this does not mean to say that everyone has to go to bed from October to February. Nor need we always go to bed from 10 pm to 7 am.

Some marine animals never sleep, although they may rest. Most sharks, for example, have to keep moving all their lives, or the flow of water through their gills will cease and lack of oxygen will kill them. The dolphins are confronted with an even worse dilemma; they must return to the surface every two or three minutes to breathe, and so can never allow themselves a moment's unconsciousness. It would be very interesting to know if sleep occurs among the creatures of the ocean abyss, where there is never any change of light, and utter darkness has reigned for 100,000,000 years.

The recent proof of the long-suspected fact that everybody dreams has led to the theory that sleep is a psychological rather than a physiological necessity; as one scientist has put it, it allows us to go safely insane for a few hours a day. This seems a very implausible explanation, and it is just as likely that dreams are a random and accidental by-product of the sleeping brain, for one would hardly expect so complex an organ to switch itself off completely. (What do electronic computers dream about?)

In any event, some prodigies, like Edison, have been able to lead active lives on two or three hours of sleep a day, while medical science has reported cases of individuals who have not slept for years at a time and have apparently been none the worse for it. Even if we cannot abolish sleep altogether, it would be an immense gain if we could concentrate it into a very few hours of really deep unconsciousness, chosen when convenient.

It seems very likely that the development of global TV and cheap telephone networks cutting across all time zones will lead inevitably to a world organized on a 24-hour basis. This alone will make it imperative to minimise sleep; and it appears that the means for doing so is already at hand.

Several years ago, the Russians put on the market a neat little 'Electric sleep apparatus' about the size of a shoe-box and weighing only five pounds. Through electrodes resting on the eyelids and the nape, low-frequency pulses are applied to the cerebral cortex, and the subject promptly lapses into profound slumber. Though this device was apparently designed for medical use, it has been reported that many Soviet citizens are using it to cut down their sleeping time to a few hours a day.*

Perhaps we shall always need the 'balm of tired minds', but we will not have to spend a third of our lives applying it. On-the other hand, there are occasions when protracted unconsciousness would be very valuable; it would be welcomed, for example, by convalescents recuperating after operations – and, above all, by space-travellers on lengthy missions. It is in this connection that serious thought is now being given to the possibility of suspended animation, which we will need if we are ever to reach the stars, or travel more than a very few light-years from the neighbourhood of the Sun.

A safe and practical form of suspended animation – which involves no medical impossibility and may indeed be regarded as an extension of anaesthesia – could have major effects upon society. Men suffering from incurable diseases might choose to leapfrog ten or twenty years, in the hope that medical science had caught up with their condition. The insane, and criminals beyond our present powers of redemption, might also be sent forward in time, in the expectation that the future could salvage them. Our descendants might not appreciate this legacy, of course, but at least they could not send it back.

All this assumes – though no one has yet proved it – that the legend of Rip Van Winkel is scientifically sound, and that the processes of ageing would be slowed down, or even checked, during suspended animation. Thus a sleeping man could travel down the centuries, stopping from time to time and exploring the future as today we explore space. There are always misfits in every age who might prefer to do this, if they were given the opportunity, so that they could see the world that will exist far beyond their normal span of life.

And this brings us to what is, perhaps, the greatest enigma of all. *Is* there a normal span of life, or do all men really die by accident? Though we now live, on the average, far longer than our ancestors, the absolute limit does not seem to have altered since records became available. The Biblical three-score-years-and-ten is still as valid as it was 4,000 years ago.

No human being has been proved to have lived more than 115 years; the much higher figures often quoted are almost certainly due to fraud or error. Man, it seems, is the longest lived of all the mammals, but some fish and tortoises may attain their second century. And trees, of course, have incredible lifespans; the oldest known living organism is a small and unprepossessing bristlecone pine in the foothills of the Sierra Nevada. It has been growing, though hardly flourishing, for 4,600 years.*

Death (though not ageing) is obviously essential for progress, both social and biological. Even if it did not perish from overpopulation, a world of immortals would soon stagnate. In every sphere of human activity, one can find examples of the stultifying influence of men who have outlived their usefulness. Yet death – like sleep – does not appear to be biologically inevitable, even if it is an evolutionary necessity.

Our bodies are not like machines; they never wear out, because the are continually rebuilt from new materials. If this process were uniformly efficient, we would be immortal. Unfortunately, after a few decades something seems to go wrong in the repair-and-maintenance department; the materials are as good as ever, but the old plans get lost or ignored, and vital services are not properly restored when they break down. It is as if the cells of the body can no longer remember the jobs they once did so well.

The way of avoiding a failure of memory is to keep better records, and perhaps one day we will be able to help our bodies to do just that. The invention of the alphabet made mental forgetfulness no longer inevitable; the more sophisticated tools of future medicine may cure physical forgetfulness, by allowing us to preserve, in some suitable storage device, the ideal prototypes of our bodies. Deviations from the norm could then be checked from time to time and corrected, before they became serious.

Because biological immortality and the preservation of youth are such potent lures, men will never cease to search for them, tantalized by the examples of creatures who live for centuries and undeterred by the unfortunate experience of Dr Faust. It would be foolish to imagine that this search will never be successful, down all the ages that lie ahead. Whether success would be desirable is quite another matter.

The body is the vehicle of the brain, and the brain is the seat of the mind. In the past, this triad has been inseparable, but it will not always be so. If we cannot prevent our bodies from disintegrating, we may replace them while there is yet time.

The replacement need not be another body of flesh and blood; it could be a machine, and this may represent the next stage in evolution. Even if the brain is not immortal, it could certainly live much longer than the body whose diseases and accidents eventually bring it low. Many years ago, in a famous series of experiments, Russian surgeons kept a dog’s head alive for some days by purely mechanical means. I do not know if they have yet succeeded with man, but I shall be surprised if they have not tried.

If you think that an immobile brain would lead a very dull sort of life, you have not fully understood what has already been said about the senses. A brain connected by wire or radio links to suitable organs could participate in any conceivable experience, real or imaginary. When you touch something, are you *really* aware that your brain is not at your fingertips, but three feet away? And would you notice the difference, if that three feet were 3,000 miles? Radio waves make such a journey more swiftly than the nervous impulses can travel along your arm.

One can imagine a time when men who still inhabit organic bodies are regarded with pity by those who have passed on to an infinitely richer mode of existence, capable of throwing their consciousness or sphere of attention instantaneously to any point on land, sea or sky where there was a suitable sensing organ. In adolescence we leave childhood behind; one day there may be a second and more portentuous adolescence, when we bid farewell to the flesh.

But even if we can keep the brain alive indefinitely, surely in the end it would be clogged with memories, overlaid like a palimpsest with so many impressions and experiences that there was no room for more? Eventually, perhaps yes, though I would repeat again that we have no idea of the ultimate capacity of a well-trained mind, even without the mechanical aids which will certainly become available. As a good round figure, a thousand years would seem to be about the ultimate limit for continuous human existence – though suspended animation might spread this millennium across far longer vistas of time.

Yet there may be a way past even this barrier, as I suggested in the novel *The City and the Stars.* This was an attempt to envisage a virtually eternal society, in the closed city of Diaspar a billion years from now. I would like to end by quoting the words in which my hero learns the facts of life from his old tutor, Jeserac:

‘A human being, like any other object, is defined by its structure – its pattern. The pattern of a man is incredibly complex; yet Nature was once able to pack that pattern into a tiny cell, too small for the eye to see.

‘What Nature can do, Man can do also, in his own way. We do not know how long the task took. A million years, perhaps – but what is that? In the end our ancestors learned to analyse and store the information that would define any specific human being – and to use that information to recreate the original.

‘The way in which information is stored is of no importance; all that matters is the information itself. It may be in the form of written words on paper, of varying magnetic fields, or patterns of electric charge. Men have used all these methods of storage, and many others. Suffice to say that long ago they were able to store themselves – or, to be more precise, the disembodied patterns from which they could be called back into existence.

‘In a little while, I shall prepare to leave this life. I shall go back through my memories, editing them and cancelling those I do not wish to keep. Then I shall walk into the Hall of Creation, but through a door that you have never seen. This old body will cease to exist, and so will consciousness itself. Nothing will be left of Jeserac but a galaxy of electrons frozen in the heart of a crystal.

‘I shall sleep, and without dreams. Then one day, perhaps a hundred thousand years from now, I shall find myself in a new body, meeting those who have been chosen to be my guardians … At first I will know nothing of Diaspar and will have no memories of what I was before. Those memories will slowly return, at the end of my infancy, and I will build upon them as I move forward into my new cycle of existence.

‘This is the pattern of our lives … We have all been here many, many times before, though as the intervals of non-existence vary according to random laws this present population will never repeat itself. The new Jeserac will have new and different friends and interests, but the old Jeserac – as much of him as I wish to save – will still exist.

‘So at any moment only a hundredth of the citizens of Diaspar live and walk in its streets. The vast majority slumber in the memory banks, waiting for the signal that will call them forth onto the stage of existence once again. And so we have continuity, yet change – immortality, but not stagnation …’

Is this fantasy? I do not know; but I suspect that the truths of the far future will be stranger still. In the next chapter, we will attempt to glimpse some of them.

Epilogue

Recent work on ‘biological feedback’, when brain impulses are computer-processed and then fed back through the senses, has opened up some very exciting possibilities. It appears that after a few hours of training with this equipment, subjects can perform feats of body control matching those of the most talented adepts of yoga. (see, eg, Dave Rorvik: *When Man Becomes Machine)*

EIGHTEEN

THE OBSOLESCENCE OF MAN

About a million years ago, an unprepossessing primate discovered that his forelimbs could be used for other purposes besides locomotion. Objects like sticks and stones could be grasped – and, once grasped, were useful for killing game, digging up roots, defending or attacking, and a hundred other jobs. On the third planet of the Sun, tools had appeared; and the place would never be the same again.

The first users of tools were *not* men – a fact appreciated only in the last year or two – but prehuman anthropoids; and by their discovery they doomed themselves. For even the most primitive of tools, such as a naturally pointed stone that happens to fit the hand, provides a tremendous physical and mental stimulus to the user. He has to walk erect; he no longer needs huge canine teeth – since sharp flints can do a better job – and he must develop manual dexterity of a high order. These are the specifications of *Homo sapiens;* as soon as they start to be filled, all earlier models are headed for rapid obsolescence. To quote Professor Sherwood Washburn of the University of California's Anthropology Department: 'It was the success of the simplest tools that started the whole trend of human evolution and led to the civilizations of today.'

Note that phrase – 'the whole trend of human evolution'. The old idea that Man invented tools is therefore a misleading half-truth; it would be more accurate to say that *tools invented Man*. They were very primitive tools, in the hands of creatures who were little more than apes. Yet they led to us – and to the eventual extinction of the apeman who first wielded them.

Now the cycle is about to begin again; but neither history nor prehistory ever exactly repeats itself, and this time there will be a fascinating twist in the plot. The tools the apemen invented caused them to evolve into their successor, *Homo sapiens.* The tool we have invented *is* our successor. Biological evolution has given way to a far more rapid process – technological evolution. To put it bluntly and brutally, the machine is going to take over.

This, of course, is hardly an original idea. That the creation of Man's brain might one day threaten and perhaps destroy him in such a tired old *cliche* that no self-respecting science-fiction magazine would dare to use it. It goes back, through Čapek's *RUR*, Samuel Butler's *Erewhon,* Mary Shelley's *Frankenstein* and the Faust legend to the mysterious but perhaps not wholly mythical figure of Daedalus, King Minos' one-man Office of Scientific Research. For at least 3,000 years, therefore, a vocal minority of mankind has had grave doubts about the ultimate outcome of technology. From the self-centred, human point of view, these doubts are justified. But that, I submit, will not be the only – or even the most important – point of view for much longer.

When the first large-scale electronic computers appeared some twenty years ago, they were promptly nick-named 'Giant Brains' – and the scientific community, as a whole, took a poor view of the designation. But the scientists objected to the wrong word. The electronic computers were not *giant* brains; they were dwarf brains, and they still are, though they have grown a hundredfold within less than one generation of mankind. Yet even in their present flint-axe stage of evolution, they have done things which not long ago almost everyone would have claimed to be impossible – such as translating from one language to another, composing music and playing a fair game of chess. And much more important than any of these infant *jeux d'esprit* is the fact that they have breached the barrier between brain and machine.

This is one of the greatest – and perhaps one of the last – breakthroughs in the history of human thought, like the discovery that the Earth moves round the Sun, or that Man is part of the animal kingdom, or that $E = mc^2$. All these ideas took time to sink in, and were frantically denied when first put forward. In the same way it will take a little while for men to realize that machines can not only think, but may one day think them off the face of the Earth.

At this point you may reasonably ask: 'Yes – but what do you mean by *think?*' I propose to side-step that question, using a neat device due to the English mathematician A. M. Turing. Turing imagined a game played by two teleprinter operators in separate rooms – this impersonal link being used to remove all clues given by voice, appearance and so forth. Suppose that one operator was able to ask the other any questions he wished, and the other had to make suitable replies. If, after some hours or days of this conversation, the questioner could not decide whether his telegraphic acquaintance was human or purely mechanical, then he could hardly deny that he/it was capable of thought. An electronic brain that passed this test would, surely, have to be regarded as an intelligent entity. Anyone who argued otherwise would merely prove that he was less intelligent than the machine; he would be a splitter of non-existent hairs, like the scholar who proved that the *Odyssey* was not written by Homer but by another man of the same name.

We are still decades – but not centuries – from building such a machine, yet already we are sure that could be done. If Turing's experiment is never carried out, it will merely be because the intelligent machines of the future will have better things to do with their time than conduct extended conversation with men. I often talk with my dog, but I don't keep it up for long.

The fact that the great computers of today are still highspeed morons, capable of doing nothing beyond the scope of the instructions carefully programmed into them, has given many people a spurious sense of security. No machine, they argue, can possibly be more intelligent than its makers – the men who designed it, and planned its functions. It may be a million times faster in operation, but this is quite irrelevant. Anything and everything that an electronic brain can do must also be within the scope of a human brain, if it had sufficient time and patience. Above all, no machine can show originality or creative power or the other attributes which are fondly labelled 'human'.

The argument is wholly fallacious; those who still bring it forth are like the buggy-whip makers who used to poke fun at stranded Model T's. Even if it were true, it could give no comfort, as a careful reading of these remarks by Dr Norbert Wiener will show: 'This attitude (the assumption that machines cannot possess any degree of originality) in my opinion should be rejected entirely … It is my thesis that machines can and do transcend some of the limitations of their designers … It may well be that in principle we cannot make any machine, the elements of whose behaviour we cannot comprehend sooner or later. This does not mean in any way that we shall be able to comprehend them in substantially less time than the operation of the machine, nor even within any given number of years or generations … This means that though they are theoretically subject to human criticism, such criticism may be ineffective until a time long after it is relevant.'

In other words, even machines *less* intelligent than men might escape from our control by sheer speed of operation. And in fact, there is every reason to suppose that machines will become much more intelligent than their builders, as well as incomparably faster.

There are still a few authorities who refuse to grant any degree of intelligence to machines, now or in the future. This attitude shows a striking parallel to that adopted by the chemists of the early nineteenth century. It was known then that all living organisms are formed from a few common elements – mostly carbon, hydrogen, oxygen and nitrogen – but it was firmly believed that the materials of life could not be made from 'mere' chemicals alone. There must be some other ingredient – some essence or vital principle, for ever unknowable to man. No chemist could ever take carbon, hydrogen and so forth and combine them to form any of the substances upon which life was based. There was an impassable barrier between the worlds of ‘inorganic’ and ‘organic’ chemistry.

This *mystique* was destroyed in 1828, when Wöhler synthesized urea, and showed that there was no difference at all between the chemical reactions taking place in the body, and those taking place inside a retort. It was a terrible shock to those pious souls who believed that the mechanics of life must always be beyond human understanding or imitation. Many people are equally shocked today by the suggestion that machines can think, but their dislike of the situation will not alter it in the least.

Since this is not a treatise on computer design, you will not expect me to explain how to build a thinking machine. In fact, it is doubtful if any human being will ever be able to do this in detail, but one can indicate the sequence of events that will lead from *H. sapiens* to *M. sapiens.* The first two or three steps on the road have already been taken; machines now exist that can learn by experience, profiting from their mistakes and – unlike human beings – never repeat them. Machines have been built which do not sit passively waiting for instructions, but which explore the world around them in a manner which can only be called inquisitive. Others look for proofs of theorems in mathematics or logic, and sometimes come up with surprising solutions that had never occurred to their makers.

These faint glimmerings of original intelligence are confined at the moment to a few laboratory models; they are wholly lacking in the giant computers that can now be bought by anyone who happens to have a few hundred thousand pounds to spare. But machine intelligence will grow, and it will start to range beyond the bounds of human thought as soon as the second generation of computers appears – the generation that has been designed, not by men, but by other, ‘almost intelligent’ computers. And not only designed, but also built – for they will have far too many components for manual assembly.

It is even possible that the first genuine thinking machines may be *grown* rather than constructed; already some crude but very stimulating experiments have been carried out along these lines. Several artificial organisms have been built which are capable of re-wiring themselves to adapt to changing circumstances. Beyond this there is the possibility of computers which will start from relatively simple beginnings, be programmed to aim at specific goals, and search for them by constructing their own circuits, perhaps by growing networks of threads in a conducting medium. Such a growth may be no more than a mechanical analogy of what happens to every one of us in the first nine months of our existence.

All speculations about intelligent machines are inevitably conditioned –

indeed, inspired – by our knowledge of the human brain, the only thinking device currently on the market. No one, of course, pretends to understand the full workings of the brain, or expects that such knowledge will be available in any foreseeable future. (It is a nice philosophical point as to whether the brain can ever, even in principle, understand itself.) But we do know enough about its physical structure to draw many conclusions about the limitations of ‘brains’ – whether organic or inorganic.

There are approximately 10 billion separate switches – or neurones – inside your skull, ‘wired’ together in circuits of unimaginable complexity. Ten billion is such a large number that, until recently, it could be used as an argument against the achievement of mechanical intelligence. About twenty years ago a famous neurophysiologist made a statement (still produced like some protective incantation by the advocates of cerebral supremacy) to the effect that an electronic model of the human brain would have to be as large as the Empire State Building, and would need Niagara Falls to keep it cool when it was running.

This must now be classed with such interesting pronouncements as, ‘No heavier-than-air machines will ever be able to fly’. For the calculation was made in the days of the vacuum tube (remember it?), and the transistor has now completely altered the picture. Indeed – such is the state of technological progress today – the transistor itself is being replaced by still smaller and faster devices, based upon abstruse principles of quantum physics. If the problem was merely one of space, today’s electronic techniques would allow us to pack a computer as complex as the human brain on to a single floor of the Empire State Building.

Interlude for agonizing reappraisal. It’s a tough job keeping up with science, and since I wrote that last paragraph the Marquardt Corporation’s Astro Division has announced a new memory device which could store inside a six-foot cube *all information recorded during the last 10,000 years.* This means, of course, not only every book ever printed, but *everything* ever written in *any* language on paper, papyrus, parchment or stone. It represents a capacity untold millions of times greater than that of a single human memory, and though there is a mighty gulf between merely storing information and thinking creatively – the Library of Congress has never written a book – it does indicate that mechanical brains of enormous power could be quite small in physical size.

This should not surprise anyone who remembers how radios have shrunk from the bulky cabinet models of the Thirties to the vest-pocket (yet much more sophisticated) transistor sets of today. And the shrinkage is just gaining momentum, if I may employ such a mind-boggling phrase. Radio receivers the size of lumps of sugar have now been built; before long, they will be the size not of lumps but of grains, for the slogan of the micro-miniaturization experts is 'If you can see it, it's too big.'

Just to prove that I am not exaggerating, here are some statistics you can use on the next hi-fi fanatic who takes you on a tour of his wall-to-wall installation. During the 1950s, the electronic engineers learned to pack up to 100,000 components into one cubic foot. (To give a basis of comparison, a good hi-fi set may contain two or three hundred components, a domestic radio about a hundred.) At the beginning of the 1960s, the attainable figure was about a million components per cubic foot; in the 1970s, thanks to developments in solid-state engineering, it was heading for 100,000,000.

Fantastic though this last figure is, the human brain surpasses it by a thousandfold, packing its 10 billion neurones into a *tenth* of a cubic foot. And although smallness is not necessarily a virtue, even this may be nowhere near the limit of possible compactness.

For the cells composing our brains are slow-acting, bulky and wasteful of energy – compared with the scarcely more than atom-sized computer elements that are theoretically possible. The mathematician, John von Neumann, once calculated that electronic cells could be 10 billion times more efficient than protoplasmic ones; already they are a million times swifter in operation, and speed can often be traded for size. If we take these ideas to their ultimate conclusion, it appears that a computer equivalent in power to one human brain need be no bigger than a matchbox.

This slightly shattering thought becomes more reasonable when we take a critical look at flesh and blood and bone as engineering materials. All living creatures are marvellous, but let us keep our sense of proportion. Perhaps the most wonderful thing about Life is that it works at all, when it has to employ such extraordinary materials, and has to tackle its problems in such roundabout ways.

As a perfect example of this, consider the eye. Suppose *you* were given the problem of designing a camera – for that, of course, is what the eye is – which *has to be constructed entirely of water and jelly*, without using a scrap of glass, metal or plastic. Obviously, it can't be done …

You're quite right; the feat is impossible. The eye is an evolutionary miracle, but it's a lousy camera. You can prove this while you're reading the next sentence.

Here's a medium-length word: photography. Close one eye and keep the other fixed – repeat, *fixed* – on that centre 'g'. You may be surprised to discover that – unless you cheat by altering the direction of your gaze – you cannot see the whole word clearly. It fades out three or four letters to the right and left.

No camera ever built – even the cheapest – has as poor an optical performance as this. For colour vision also, the human eye is nothing to boast about; it can operate only over a small band of the spectrum. To the worlds of the infra-red and ultra-violet, visible to bees and other insects, it is completely blind.

We are not conscious of these limitations because we have grown up with them, and indeed if they were corrected the brain would be quite unable to handle the vastly increased flood of information. But let us not make a virtue of a necessity; if our eyes had the optical performance of even the cheapest miniature camera, we would live in an unimaginably richer and more colourful world.

These defects are due to the fact that precision scientific instruments simply cannot be manufactured from living materials. With the eye, the ear, the nose – indeed, all the sense organs – evolution has performed a truly incredible job against fantastic odds. But it will not be good enough for the future; indeed, it is not good enough for the present.

There are some senses that do not exist, that can probably never be provided by living structures, and which we need in a hurry. On this planet, to the best of our knowledge, no creature has ever developed organs that can detect radio waves or radioactivity. Though I would hate to lay down the law and claim that nowhere in the universe can there be organic Geiger counters or living TV sets, I think it highly improbable. There are some jobs that can be done only by vacuum tubes or magnetic fields or electron beams, and are therefore beyond the capability of purely organic structures.

There is another fundamental reason why living machines such as you and I cannot hope to compete with non-living ones. Quite apart from our poor materials, we are handicapped by one of the toughest engineering specifications ever issued. What sort of performance would you expect from a machine which has to grow several billionfold during the course of manufacture – and which has to be completely and continuously rebuilt, molecule by molecule, every few weeks? This is what happens to all of us, all the time; you are not the man you were last year, in the most literal sense of the expression.

Most of the energy and effort required to run the body goes into its perpetual tearing down and rebuilding – a cycle completed every few weeks. Cities like London or New York, which are very much simpler structures than a man, take hundreds of times longer to remake themselves. When one tries to picture the body’s myriads of building contractors and utility companies all furiously at work, tearing up arteries and nerves and even bones, it is astonishing that there is any energy left over for the business of thinking.

Now I am perfectly well aware that many of the 'limitations' and 'defects' just mentioned are nothing of the sort, looked at from another point of view. Living creatures, because of their very nature, can evolve from simple to complex organisms. They may well be the only path by which intelligence can be attained, for it is a little difficult to see how a lifeless planet can progress directly from metal ores and mineral deposits to electronic computers by its own unaided efforts.

Though intelligence can only arise from life, it may then discard it. Perhaps at a later stage, as the mystics have suggested, it may also discard matter; but this leads us into realms of speculation which an unimaginative person like myself would prefer to avoid.

One often-stressed advantage of living creatures is that they are self-repairing and reproduce themselves with ease – indeed with enthusiasm. This superiority over machines will be short-lived; the general principles underlying the construction of self-repairing and self-reproducing machines have already been worked out. There is, incidentally, something ironically appropriate at the fact that A. M. Turing, the brilliant mathematician who pioneered in this field and first indicated how thinking machines might be built, apparently committed suicide a few years after publishing his results. It is very hard not to draw a moral from this.

The greatest single stimulus to the evolution of mechanical – as opposed to organic – intelligence is the challenge of space. Only a vanishingly small fraction of the universe is directly accessible to mankind, in the sense that we can live there without elaborate protection or mechanical aids. If we generously assume that humanity's potential *lebensraum* extends to a height of three miles, over the whole Earth, that gives us a total of some half billion cubic miles. At first sight this is an impressive figure, especially when you remember that the entire human race could be packaged into a one-mile cube. But it is absolutely nothing, when set against Space with a capital 'S'. Our present telescopes, which are certainly not the last word on the subject, sweep a volume at least a million million million million million million million million million million times greater.

Though such a number is, of course, utterly beyond conception, it can be given a vivid meaning. If we reduce the known universe to the size of the Earth, then the portion in which *we* can live without space-suits and pressure cabins is about the size of a single atom.

It is true that, one day, we are going to explore and colonise many other atoms in this Earth-sized volume, but it will be at the cost of tremendous technical efforts, for most of our energies will be devoted to protecting our frail and sensitive bodies against the extremes of temperature, pressure or gravity found in space and on other worlds. Within very wide limits, machines are indifferent to these extremes. Even more important, they can wait patiently through the years and the centuries that will be needed for travel to the far reaches of the universe.

Creatures of flesh and blood such as ourselves can explore space and win control over infinitesimal fractions of it. But only creatures of metal and plastic can ever really conquer it, as indeed they have already started to do. The tiny brains of our Mariners and Pioneers barely hint at the mechanical intelligences that will one day be launched at the stars.

It may well be that only in space, confronted with environments fiercer and more complex than any to be found upon this planet, will intelligence be able to reach its fullest stature. Like other qualities, intelligence is developed by struggle and conflict; in the ages to come, the dullards may remain on placid Earth, and real genius will flourish only in Space – the realm of the machine, not of flesh and blood.

A striking parallel to this situation can already be found on our planet. Some millions of years ago, the most intelligent of the mammals withdrew from the battle of the dry land and returned to their ancestral home, the sea. They are still there, with brains larger and potentially more powerful than ours. But (as far as we know) they do not use them; the static environment of the sea makes little call upon intelligence. The porpoises and whales, who might have been our equals and perhaps our superiors had they remained on land, now race in simple-minded and innocent ecstasy beside the new sea-monsters carrying a hundred megatons of death. Perhaps they, not we, made the right choice; but it is too late to join them now.

If you have followed me so far, the protoplasmic computer inside your skull should now be programmed to accept the idea – at least for the sake of argument – that machines can be both more intelligent and more versatile than men, and may well be so in the very near future. So it is time to face the question: ‘Where does that leave Man?’

I suspect that this is not a question of very great importance – except, of course, to Man. Perhaps the Neanderthalers made similar plaintive noises, around 100,000 B.C., when *H. sapiens* appeared on the scene, with his ugly vertical forehead and ridiculous protruding chin. Any Paleolithic philosopher who gave his colleagues the right answer would probably have ended up in the cooking-pot; I am prepared to take that risk.

The short-term answer may indeed be cheerful rather than depressing. There may be a brief Golden Age when men will glory in the power and range of their new partners. Barring war, this Age lies directly ahead of us. As Dr Simon Ramo put it recently: ‘The extension of the human intellect by electronics will become our greatest occupation within a decade.’ That is undoubtedly true, if we bear in mind that at a somewhat later date the word ‘extension’ may be replaced by ‘extinction’.

One of the ways in which thinking machines will be able to help us is by taking over the humbler tasks of life, leaving the human brain free to concentrate on higher things. (Not, of course, that this is any guarantee that it will do so.) For a few generations, perhaps, every man will go through life with an electronic companion, which may be no bigger than today’s transistor radios. It will ‘grow up’ with him from infancy, learning his habits, his business affairs, taking over all the minor chores like routine correspondence and income tax returns and engagements. On occasion it could even take its master’s place, keeping appointments he preferred to miss, and then reporting back in as much detail as he desired. It could substitute for him over the telephone so completely that no one would be able to tell whether man or machine was speaking; a century from now, Turing’s ‘game’ may be an integral part of our social lives, with complications and possibilities which I leave to the imagination.

You may remember that delightful robot, Robbie, from the movie, *Forbidden Planet.* (One of the three or four movies so far made that anyone interested in science-fiction can point to without blushing; the fact that the plot was Shakespeare’s doubtless helped.) I submit, in all seriousness, that most of Robbie’s abilities – together with those of a better-known character, Jeeves – will one day be incorporated in a kind of electronic companion-secretary-valet. It will be much smaller and neater than the walking juke-boxes or mechanised suits of armour which Hollywood presents, with typical lack of imagination, when it wants to portray a robot. And it will be extremely talented, with quick-release connectors allowing it to be coupled to an unlimited variety of sense-organs and limbs. It would, in fact, be a kind of general purpose, disembodied intelligence that could attach itself to whatever tools were needed for any particular occasion. One day it might be using microphones or electric typewriters or TV cameras; on another, automobiles or aeroplanes – or the bodies of men and animals.

And this is, perhaps, the moment to deal with a conception which many people find even more horrifying than the idea that machines will replace or supersede us. It is the idea already mentioned in the last chapter, that they may combine with us.

I do not know who first thought of this; probably the physicist, J. D. Bernal, who in 1929 published an extraordinary book of scientific predictions called *The*

World, the Flesh and the Devil. In this slim volume (recently reprinted by the Indiana University Press), Bernal decided that the numerous limitations of the human body could be overcome only by the use of mechanical attachments or substitutes – until, eventually, all that might be left of Man's original organic body would be the brain.

This idea is already far more plausible than when Bernal advanced it, for in the last few decades we have seen the development of mechanical hearts, kidneys, lungs and other organs, and the wiring of electronic devices directly into the human nervous system.

Olaf Stapledon developed this theme in his wonderful history of the future, *Last and First Men,* imagining an age of immortal 'Giant Brains', many yards across, living in beehive-shaped cells, sustained by pumps and chemical plants. Though completely immobile, their sense-organs could be wherever they wished, so their centre of awareness – or consciousness, if you like – could be anywhere on Earth or in the space above it. This is an important point which we – who carry our brains around in the same fragile structure as our eyes, ears and other sense-organs, often with disastrous results – may easily fail to appreciate. Given perfected telecommunications, a fixed brain is no handicap, but rather the reverse. Your present brain, totally imprisoned behind its walls of bone, communicates with the outer world and receives its impressions of it over the telephone wires of the central nervous system – wires varying in length from a fraction of an inch to several feet. *You would never know the difference if those 'wires' were actually hundreds or thousands of miles long, or included mobile radio links, and your brain never moved at all.*

In a crude way – yet one that may accurately foreshadow the future – we have already extended our visual and tactile senses away from our bodies. The men who now work with radio-isotopes, handling them with remotely controlled mechanical fingers and observing them by television, have achieved a partial separation between brain and sense organs. They are in one place; their minds effectively in another.

Recently the word 'Cyborg' (cybernetic organism) has been coined to describe machine-animals of the type we have been discussing. Doctors Manfred Clynes and Nathan Kline of Rockland State Hospital, Orangeburg, New York, who invented the name, define a Cyborg in these stirring words: 'An exogenously extended organizational complex functioning as a homeostatic system.' To translate, this means a body which has machines hitched to it, or built into it, to take over or modify some of its functions.

I suppose one could call a man in an iron lung a Cyborg, but the concept has far wider implications than this. One day we may be able to enter into temporary unions with any sufficiently sophisticated machines, thus being able not merely to control but to *become* a spaceship or a submarine or a TV network. This would give far more than purely intellectual satisfaction; the thrill that can be obtained from driving a racing car or flying an aeroplane may be only a pale ghost of the excitement our great-grandchildren may know, when the individual human consciousness is free to roam at will from machine to machine, through all the reaches of sea and sky and space.

But how long will this partnership last? Can the synthesis of Man and Machine ever be stable, or will the purely organic component become such a hindrance that it has to be discarded? If this eventually happens – and I have given good reasons for thinking that it must – we have nothing to regret, and certainly nothing to fear.

The popular idea, fostered by comic strips and the cheaper forms of science-fiction, that intelligent machines must be malevolent entities hostile to man, is so absurd that it is hardly worth wasting energy to refute it. I am almost tempted to argue that only unintelligent machines can be malevolent; anyone who has tried to start a balky outboard will probably agree. Those who picture machines as active enemies are merely projecting their own aggressive instincts, inherited from the jungle, into a word where such things do not exist. The higher the intelligence, the greater the degree of cooperativeness. If there is ever a war between men and machines, it is easy to guess who will start it.

Yet however friendly and helpful the machines of the future may be, most people will feel that it is a rather bleak prospect for humanity if it ends up as a pampered specimen in some biological museum – even if that museum is the whole planet Earth. This, however, is an attitude I find it impossible to share.

No individual exists for ever; why should we expect our species to be immortal? Man, said Nietzsche, is a rope stretched between the animal and the superman – a rope across the abyss. That will be a noble purpose to have served.

NINETEEN

THE LONG TWILIGHT

Looking back over the preceding chapters, I am aware of numerous inconsistencies and some omissions. As for the first, I am unrepentant, for the reasons given in the Introduction. In attempting to explore rival and indeed contradictory possibilities, I have tried to go to the end of the line in each case; sometimes this has led to a sense of pride in Man's past and future achievements – sometimes to a conviction that we represent only a very early stage in the story of evolution, destined to pass away leaving little mark on the Universe. Every reader must choose his own standpoint here; but whatever position he adopts, it would be advisable to leave a line of retreat.

Concerning the omissions, some are due to a frank lack of interest on my part, others to a feeling that I did not have the necessary qualifications to discuss them. That last reason accounts for the fact that medical and biological themes were not developed in much more detail. It seems perfectly possible that many future achievements of production, sensing, data-processing and manufacture may be based on living or quasi-living creatures, rather than inorganic devices. Nature provides at zero cost, so many marvellous mechanisms that it seems foolish not to employ them to the utmost. I have little doubt that our descendants will use many intelligent animals to do jobs that could otherwise be performed only by very expensive and sophisticated robots.

In this connexion, I might have discussed the attempts now being made by Dr Lilly and others to establish communication with dolphins.* I might have said a good deal more about the possibility of contacting extra-terrestrial intelligences by radio or laser (coherent light) beams. One or both of these objectives will be achieved, sooner or later, but both open up vistas so unlimited that it is fruitless to speculate about them; there are no boundary posts here, as yet, to mark the border between science and fantasy.

While on the subject of communication, I might also have discussed the urgent problem of communication between human beings. The development of 'machine languages' for computers is, unquestionably, going to have considerable feedback on linguistics. Some scholars have already attempted to develop logical languages, free from the ambiguities and defects of all the existing ones. This is a far more ambitious project than devising yet another Esperanto or Interlingua; it goes to the very basis of thought. (One such effort is described in the article LOGLAN in *Scientific American* for June 1960.) Though I suspect that a logical language is one in which it is impossible to write poetry or love-letters, its development should be welcomed. Perhaps the future will have two languages – one for thinking and one for feeling. The second might be specific to the human race, but the first might have universal application.

The control of weather, and ultimately of climate, is another subject which might have been discussed at some length. Apart from its obvious terrestrial importance, this will eventually lead to what has been called 'planetary engineering' – the large-scale modification of other celestial bodies to make them inhabitable. The search for such activities, elsewhere in the universe, may be a major project for the astronomers of the future. Indeed, it has been a minor one in the past; the famous debate concerning the Martian 'canals' is proof of this.

Certain types of symmetrical or ordered structure, certain kinds of energy release, are so abnormal that they point to an intelligent origin. When the energy equivalent of several megatons appears in an area a few miles across, it can be a volcano; when it appears at a point source, it can only be a bomb.

The radio astronomers are now discovering some most extraordinary phenomena in other galaxies; Virgo A (Messier 87), for example, has a brilliant jet extending from its nucleus, like a searchlight beam hundreds of light-years long. What is so peculiar about this jet is the concentration of energy it contains – perhaps equivalent to that of millions of supernovae, or the radiation from millions of *millions* of ordinary stars. In fact, to power this jet, a mass equivalent to about a hundred suns would have to be completely annihilated!

This is totally inexplicable in terms of any known natural process; it is like comparing an H-bomb to a geyser. The chances are that there *is* a natural explanation, which we have not yet discovered, but it is tempting to speculate about the alternative. Given sufficient time, rational beings might attain the power to manipulate not merely planets, not merely stars, but the galaxies themselves. If the jet from M.87 is artificial, what is its purpose? Is it an attempt to signal across intergalactic space? A tool of cosmic engineers? A weapon? Or some by-product of incomprehensible religions and philosophies – as on our own planet, the Great Pyramid is a gigantic symbol of a now almost wholly alien mentality?

Such projects would demand vistas of time, and continuity of cultures, on a scale inconceivable to us. The time is there; of that there is no doubt. Each generation of astronomers multiplies the age of the universe by ten; the current estimate appears to be about 25 billion years. If we say that human civilization has existed for about a millionth of the age of this galaxy, we may not be far wrong.

But it also appears that the past duration of the galaxy is a mere flicker of time, compared to the aeons that may lie ahead. At their present lavish rate of radiation, stars such as the Sun can continue to burn for billions of years; then, after various internal vicissitudes, they settle down to a more modest mode of existence as dwarf stars. The reformed stellar spendthrifts can then shine steadily for periods of time measured not in billions but in trillions (millions of millions) of years. The planets of such stars, if at the same distance from their primary as Earth (or even Mercury) would be frozen at temperatures hundreds of degrees below zero. But by the time we are considering, natural or artificial planets could have been moved sunward to huddle against the oncoming Ice Age as, long ago, our savage ancestors must have gathered around their fires to protect themselves from the cold and the creatures of the night.

In a famous elegiac passage, Bertrand Russell once remarked:

> … that all the labours of the ages, all the devotion, all the inspiration, all the noonday brightness of human genius, are destined to extinction in the vast death of the solar system, and that the whole temple of Man's achievement must inevitably be buried beneath the debris of a universe in ruin – all these things, if not quite beyond dispute, are yet so nearly certain, that no philosophy which rejects them can hope to stand.

This may be true enough; yet the ruin of the universe is so inconceivably far ahead that it can never be any direct concern of our species. Or, perhaps, of any species that now exists, anywhere in the spinning whirlpool of stars we call the Milky Way.

Our galaxy is now in the brief springtime of its life – a springtime made glorious by such brilliant blue-white stars as Vega and Sirius, and, on a more humble scale, our own Sun. Not until all these have flamed through their incandescent youth, in a few fleeting billions of years, will the *real* history of the universe begin.

It will be a history illuminated only by the reds and infrareds of dully-glowing stars that would be almost invisible to our eyes; yet the sombre hues of that all-but-eternal universe may be full of colour and beauty to whatever strange beings have adapted to it. They will know that before them lie, not the millions of years in which we measure the eras of geology, nor the billions of years which span the past lives of the stars, but years to be counted literally in trillions.

They will have time enough in those endless aeons, to attempt all things, and to gather all knowledge. They will not be like gods, because no gods imagined by our minds have ever possessed the powers they will command. But for all that, they may envy us, basking in the bright afterglow of Creation; for we knew the Universe when it was young.

Chart of the Future

The chart that follows is not, of course, to be taken too seriously, but it is both amusing and instructive to extrapolate the time-scale of past scientific achievement into the future. If it does no more, the quick summary of what has happened in the *last* 150 years should convince anyone that no present-day imagination can hope to look beyond the year 2,100. I have not even tried to do so.

Postscript

In updating this chart after ten years, I have made only four changes. Translating machines, Efficient Electric Storage and Cetacean Languages have all proved tougher than expected; they have been moved forward a decade. And Gravity Waves – originally in the mid-80s – have been moved back; they were detected in 1969.

Date	*Transportation*	*Communication Information*	*Materials Manufacture*	*Biology Chemistry*	*Physics*
1800			Steam Engines	Inorganic Chemistry	Atomic Theory
	Locomotive				
		Camera Babbage Calculator		Urea synthesized	
	Steamship				
1850		Telegraph	Machine Tools		Spectroscope Conservation of Energy
			Electricity	Organic Chemistry	
		Telephone Phonograph			Electromagnetism Evolution
	Automobile	Office Machines			
1900			Diesel Engine		
	Aeroplane		Petrol Engine	Dyes	X-Rays Electron
		Vacuum Tube	Mass Production	Genetics Vitamins	Radio-Activity
1910			Nitrogen Fixation	Plastics	
					Isotopes
		Radio			
					Quantum Theory
1920				Chromosomes Genes	
					Relativity Atomic Structure
1930				Language of Bees Hormones	Indeterminacy Wave Mechanics Neutron
		TV			
1940	Jet Rocket Helicopter	Radar			
		Tape Recorders Electronic Computers	Magnesium from Sea	Synthetics Antibiotics	Uranium Fission Accelerators
1950		Cybernetics Transistor Maser	Atomic Energy Automation	Silicones	Radio Astronomy
	G.E.M. Satellite	Laser Satellite	Fusion Bomb	Tranquillisers Genetic Code	I.G.Y. Parity Overthrown

	Space Lab.				
1970	Lunar Landing				Gravity Waves
	Nuclear Rocket				
1980	Planetary Landings				
		Personal Radio	Efficient Electric Storage	Cetacean Languages Exobiology	
1990		Translating Machines	Fusion Power	Cyborgs	
2000	Colonizing Planets	Artificial Intelligence	'Wireless' Energy		
		Global Library	Sea Mining	Time, Perception Enhancement	Subnuclear Structure
2010	Earth Probes	Telesensory Devices			
			Weather Control		
2020		Logical Languages			Nuclear Catalysts
	Interstellar Probes	Robots		Control of Heredity	
2030			Space Mining		
		Contact with Extra-Terrestrials		Bio-Engineering	
2040				Intelligent Animals	
			Transmutation		
2050	Gravity control			Suspended Animation	
		Memory Playback			
	'Space Drive'		Planetary Engineering		
2060		Mechanical Educator			Space, Time Distortion
		Coding of Artifacts		Artificial Life	
2070					
			Climate Control		
	Near-Light speeds				
2080		Machine Intelligence exceeds Man's			
	Interstellar flight				
2090	Matter Transmitter		Replicator		
	Meeting with Extra-Terrestrials	World Brain		Immortality	
2100			Astronomical Engineering		

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Glide Path (1963)*
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Imperial Earth (1975)
Fountains Of Paradise (1978)
Ghost From The Grand Banks (1990)
The Hammer Of God (1993)

With Gentry Lee
Rama II (1989)
Garden Of Rama (1991)
Rama Revealed (1993)
Cradle (1987)

Space Odyssey
1. *2001: A Space Odyssey* (1968)*
2. *2010: Odyssey Two* (1982)*
3. *2061: Odyssey Three* (1985)*
4. *3001: The Final Odyssey* (1996)*

Non-Fiction

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The View From Serendip (1977)
Astounding Days (1988)
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Collections
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Dedication

To
My Colleagues in the Institute
for Twenty-first Century Studies,
and especially to
Hugo Gernsback
who thought of everything

Arthur C. Clarke (1917 – 2008)

Sir Arthur Charles Clarke was born in Minehead, Somerset in 1917. He studied at King's College, London, receiving a BSc in physics and mathematics. During the Second World War he served in the Royal Air Force and was part of the team that developed the early warning radar defence system, an experience recounted in his 1963 novel *Glide Path*. A paper published in the October 1945 edition of *Wireless World* on the subject of geostationary satellites is widely recognised as having 'invented' the telecommunications satellite system. Clarke began publishing SF in 1946 with 'Loophole' in *Astounding Science Fiction* magazine, and soon established himself as one of the major science fiction voices of the 20th century. He won the first of three Hugo Awards for short story 'The Star' in 1956, and his 1973 novel *Rendezvous With Rama* won the Hugo, Nebula and John W. Campbell Memorial Awards. He is, though, best known as the writer and co-creator with Stanley Kubrick of the groundbreaking SF film *2001: A Space Odyssey*. A year after the release of that film, Clarke found himself beside US broadcasting legend Walter Cronkite, commentating on the historic Apollo 11 mission to place a man on the moon. Awarded the SFWA Grand Master Award in 1985 and knighted by Queen Elizabeth II in 1998, Arthur C. Clarke was a giant of modern SF and one of the premier thinkers of our time. He died at his home in Sri Lanka in March 2008.

To discover more about how the legacy of Sir Arthur is being honoured today, please visit http://www.clarkefoundation.org

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* PO Box 19285, Twentieth Street Station, Washington, DC 20036.

* See my debate with Dr Alan Watts on mysticism and technology, *At the Interface, Playboy* Magazine, January 1972.

* Throughout this book, 'billion' = a thousand million.

* The dead weight of the rocket (propellant tanks, motors, etc) would actually make the ratio very much higher, but that does not affect the argument.

* In all fairness to Dr Woolley, I would like to record that his 1936 review contained the suggestion – probably for the first time – that rockets could contribute to astronomical knowledge by making observations in ultraviolet light beyond the absorbing screen of the Earth's atmosphere. Thanks to the orbiting Astronomical Observatories and their successors, this idea has been overwhelmingly justified.

* Cherwell's influence – malign or otherwise – has been the subject of a vigorous debate since the publication of Sir Charles Snow's *Science and Government.*

* The French edition of this book rather surprised me by calling this Clarke's Second Law (see p 32 for the first, which is now rather well known.) I accept the label, and have also formulated a Third: 'Any sufficiently advanced technology is indistinguishable from magic.'

* *Against the Fall of Night* (since incorporated in *The City and the Stars).*

* Originally published in *Astounding Science Fiction* as *Under Pressure;* also as a pocket book with the title *21st Century Sub.* This story is unusual not only for its beautifully worked-out technical details, but also for its philosophical-religious content – considerably too adult for the escapist, 'main-stream' magazines.

* The Russians had one first, when their giant booster blew up in 1969.

* See Chapter 17.

* For 'large', now read 'small'. Such is progress since this chapter was written.

* To put you out of your misery, it *does* have spin.

* For the technology of Jovian exploration, see 'A Meeting With Medusa' in *The Wind From The Sun.*

* See 'Tales of Ten Worlds'.

* *At* the solar surface, there is 65,000 hp of energy to be picked up from every square yard!

* For the definitive study of this interesting universe, see the minor classic *Flatland* by 'A. Square' (E. A. Abbott), now readily available in James Newman's *World of Mathematics*. It is still an entertaining fantasy, though to most modern readers the Victorian author's pseudonym appears even more appropriate than he realized.

* H. G. Wells used this idea in *The Plattner Story,* where a man was reversed after a trip through the Fourth Dimension, being none the worse for the experience – though any surgeon who ever had to operate on him would be terribly confused. In *Technical Error* I pointed out that there might be other complications; a reversed man might starve to death in the midst of plenty, for many organic chemicals have mirror symmetry, and he might be unable to digest essential ingredients of food.

* A very thorough treatment of this whole subject will be found in J. B. S. Haldane's *On Being the Right Size* and D'Arcy Thompson's *On Magnitude,* both in Volume 2 of James Newman's *World of Mathematics.*

* I have, quite deliberately, left this chapter, (written in 1959) *completely* unaltered. For the reasons – and the updating – see the epilogue on page 211, and also the book *Voices From The Sky.*

* I can add an interesting footnote to this. While conducting a panel discussion at the New York Coliseum in October 1961 as part of the American Rocket Society's SPACE FLIGHT REPORT TO THE NATION, I remarked that it would be an excellent idea if the United States established a global TV system in time to relay the 1964 Olympics to all nations. The next day this suggestion (I do not

know its originator) was passed on to Vice-President Johnson, who was speaking at the Waldorf Astoria banquet which wound up the proceedings. The Vice-President was so impressed with the idea that he departed from his prepared text to include it; and I am now prepared to make a small bet that there will be few towns of any size in the world which will not be tuning in, live, to Tokyo in 1964.

* One of my friends, while chatting to the chief fire-walker at a Hindu shrine, once dropped a cigarette butt. The fire-walker stood on it and promptly leaped into the air. So much for the 'tough native soles' theory; it is the psychological attitude – the mental preparation – that is all-important.

* I am sorry I ever mentioned this wretched device, and to quench a further flood of letters wish to make it clear that it is only obtainable through authorized medical channels – and I do *not*, repeat not, know where it can be purchased. No further letters on the subject will be read – let alone answered …

* See *National Geographical Magazine:* March 1958.

* See *Man and Dolphin* by John C. Lilly.

* Not available as SF Gateway eBooks