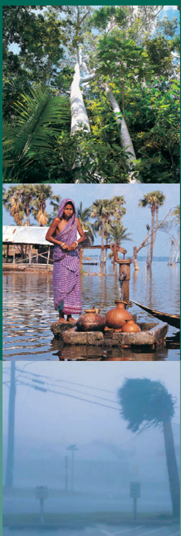
THE ROYAL SOCIETY

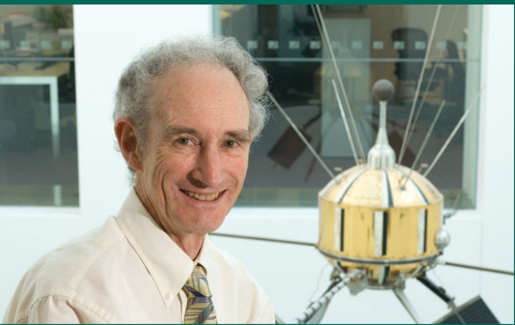


THREATS TO TOMORROW'S WORLD

ANNIVERSARY ADDRESS 2005

delivered by the President of the Royal Society
Lord May of Oxford OM AC Kt

excellence in science



LORD MAY OF OXFORD
PRESIDENT OF THE ROYAL SOCIETY

On 28 November 1660, a group of 12 people, which included Christopher Wren, met at Gresham College, London, to set up "a College for the promoting of Physico-Mathematical Experimental Learning". This event is today recognised as the founding meeting of the Royal Society, and is marked each year on 30 November (or the weekday closest to it) by Anniversary Day. It has been a tradition for the President of the Royal Society to deliver a keynote speech on Anniversary Day, addressing important issues in the world of science.

Lord Robert May of Oxford OM AC Kt completes his five-year term as President of the Royal Society on 30 November 2005. He holds a professorship jointly in the Department of Zoology, University of Oxford and Imperial College, London. Lord May has won a number of international awards, including the 1996 Crafoord Prize for "pioneering ecological research in theoretical analysis of the dynamics of populations, communities and ecosystems". Between 1995 and 2000 he was Chief Scientific Adviser to the UK Government and Head of the Office of Science and Technology. He became a member of the UK House of Lords in 2001 and was appointed to be a member of the Order of Merit in 2002.

The most important unanswered question in evolutionary biology, and more generally in the social sciences, is how co-operative behaviour evolved and can be maintained in human or other animal groups and societies[1]. At first sight, the answer may seem obvious: if you are a marmot, the small risk attendant on giving an alarm call is outweighed by the larger benefit you derive from alarm calls from other group members. The problem is the vulnerability of any such system to "cheating" – enjoying the defensive group benefit, but yourself never incurring the risk of uttering an alarm call. Such "cheats" prosper in evolutionary terms, enjoying the group benefits without the costs and, by so prospering, making it difficult for the co-operative benefits to be maintained. An example closer to home in recent years is the decline in voluntary up-take of the MMR vaccine in the UK (seeking to avoid any putative risk to your children, whilst implicitly relying on others to keep "herd immunity" high by vaccinating their children), resulting in rising incidence of measles[2].

This may seem a very odd way to begin my valedictory Anniversary Address. But I will proceed to speculate that the co-operative mechanisms which enable complex human societies to flourish are in many ways inimical to the authority-questioning values of the Enlightenment. Next I will suggest that the advances in scientific understanding that are the legacy of the deliberately experimental and fact-based Enlightenment have resulted in today's world being – to borrow a phrase – "the best of times and the worst of times". The remainder of the Address will survey some specific threats to tomorrow's world, in the form of climate change, diminishing biological diversity, and new or re-emerging diseases. The increasingly deliberate internationalisation of scientific institutions, particularly in response to the above-noted problems, will be emphasised. I conclude with the worrying question raised in Donald Kennedy's recent *Science* editorial[3] on "Twilight for the Enlightenment?".

Enlightenment science and its consequences

We can understand how co-operative behaviour is maintained in small and relatively isolated groups, where members are closely related. In oversimplified terms, cheating has a cost, by hurting the other group members who, to some degree, share the cheater's genes[4]. Such mechanisms are particularly important in some insects with peculiar genetic structures (with sisters more closely related than are offspring and parents), and may have been influential in the small bands of human hunter-gatherers which account for 95% or more of *Homo sapiens'* history. But with the beginning of settled agriculture some 10,000 years ago, and the subsequent aggregation of humans into towns and then cities, kin-selection, even reinforced by propensity for tribal loyalty, is clearly inadequate to maintain social cohesion, and more complex mechanisms were required. We can describe what happened, but I believe we still lack any substantial understanding of the evolutionary and cultural mechanisms which drove the process. Clearly language is a prerequisite. Moving beyond creation myths to an established hierarchy of authority figures who are the Creator's or Creators' representatives/enforcers on the terrestrial plane would seem to promote organisational stability, and help rationalise the assent of the governed.

Such societies are not inconsistent with innovation and exploration, particularly if focused on practical things. They can also be good at "what" questions, and even "how" questions. "Why" questions can be more difficult. I can see how, in such an authoritarian society, if the sanctioned wisdom is that heavy objects fall faster than light ones, it is not a good idea to pursue experimental tests. In other words, there is substance in the glib statement that it can be "adaptive" genuinely to believe that life is guided by the unfathomable wishes of some supernatural being.

Today, we value the questioning interlocution called the "Socratic Method". But even in Socrates' Athens, so welcoming to many forms of philosophical discourse, uncomfortable questions could – as Socrates himself discovered - incur a death penalty. Fourteenth century China, more technically advanced than the Europe of the time, had a vast fleet of ships poised on a voyage of global exploration. The Emperor, perhaps rightly fearing the disruptive consequences of such exposure to the unfamiliar, halted the project and burned the ships. In short, I guess that the same ill-understood circumstances that allow complex human societies to arise and persist also – and perhaps necessarily – have elements that are strongly antithetic to the values of the Enlightenment.

What are these values? They are tolerance of diversity, respect for individual liberty of conscience, and above all recognition that an ugly fact trumps a beautiful theory or a cherished belief. All ideas should be open to questioning, and the merit of ideas should be assessed on the strength of the evidence that supports them and not on the credentials or affiliations of the individuals proposing them. It is not a recipe for a comfortable life, but it is demonstrably a powerful engine for understanding how the world actually works and for applying this understanding.

The Royal Society is a quintessential product of the Enlightenment. In his excellent recent history of the Royal Society's early years, John Gribbin[5] writes "The Royal Society itself, although allegedly founded on Baconian principles, certainly never took upon itself any role in the practical application of science to the immediate direct benefit of humankind; if anything, it did the reverse, encouraging speculative investigation of the world by people interested in knowledge for its own sake, not for its practical utility." Were this true, it does indeed conflict with Farrington's[6] account of the Baconian ideal: "The story of Francis Bacon is that of a life devoted to a great idea. The idea gripped him as a boy, grew with the varied experience of his life, and occupied him on his deathbed. The idea is a commonplace today, partly realised, partly tarnished, still often misunderstood; but in his day it was a novelty. It is simply that knowledge ought to bear fruit in works, that science ought to be applicable to industry, that men ought to organise themselves as a sacred duty to improve and transform the conditions of life." In fact, I think one of Robert Hooke's wonderful lists testifies to the Royal Society's concern both with fundamental understanding and with practical applications.

Certainly by the time of Joseph Banks' Presidency (1778-1820), and later with Wedgewood, Faraday, Armstrong, and others, the Royal Society was engaged across the

Hookes' List[7]

Theory	Improving
– of motion	– shipping
– of light	– watch
– of gravity	– opticks
– of magnetiks	– engines for trade
– of gunpowder	– engines for carriage
– of the heavens	

spectrum not only of basic knowledge and innovative application, but also policy issues.

Ever expanding its fractal frontiers – the more we know, the more there is to know – the resulting scientific understanding has hugely changed the world, particularly over the past century and at an ever accelerating rate.

As a direct consequence, we live in the best of times: healthier, better fed, and with more energy subsidies than ever before. Basic understanding of the life sciences, especially with respect to infectious diseases, has resulted in average life expectancy at birth on the planet today being 64 years, up from 46 years only 50 years ago; the gap in life expectancy between the developed and developing worlds has correspondingly shrunk from 26 years to a still disgraceful 12. Over the past 35 years, global food production has doubled, on only 10% more land, while the human population has increased 60%; the problem of malnourishment is one of inequitable distribution, a problem which has been with us since the dawn of agriculture. The average inhabitant of the globe enjoys daily energy subsidies of 14 times the energy needed to maintain basic metabolic processes (which is essentially all our hunter-gatherer ancestors had). Although there are large and inequitable differences hidden in such an average, these unprecedented energy subsidies are washing away hierarchies of servitude and consequent class structure.

But we also live in – or more accurately, on the brink of – the worst of times. The well-intentioned actions that gave us better health, more food, more energy all have unintended adverse consequences, which we are only just beginning fully to appreciate. It took essentially all of human history to reach the first 1 billion people, around 1830; a century to double that; 40 years to double again to 4 billion around 1970. Today we are 6.5 billion, headed, barring catastrophe, to around 9 billion by 2050. The total number of people our planet can sustainably support depends on the assumptions you make[8]. But given that we currently sequester one quarter to one half of all net terrestrial primary productivity to our use[9] – a circumstance without precedent by any single species in the history of life on Earth – we are likely already to be at or beyond Earth's sustainable carrying capacity. Turning to food, we could not feed today's population with yesterday's agriculture, and it is doubtful whether we can feed tomorrow's with today's agriculture. The Green Revolution's doubling of food production involved, amongst other things, massive inputs of fossil-fuel energy subsidised fertilizers; around the globe, more than half of all the atoms of nitrogen and phosphorus in green plant material that grew last year came from artificial fertilizers, rather than the natural biogeochemical cycles that built the biosphere and which struggle to maintain it. The consequent impacts of habitat loss and other disturbing factors upon the diversity of plants and other animals with which we share our planet is only just beginning to be fully appreciated. And 90% of the energy subsidies that make daily life easier put the greenhouse gas carbon dioxide into the atmosphere, to an extent that has begun to change the global climate in a deeply serious way.

In what follows, I concentrate on three particular problems: climate change, biological diversity, infectious diseases. In each case, the problems are essentially global, not recognising the boundaries between human states. Correspondingly, the involvement of the scientific community – in basic understanding, in practical measures, and in policy recommendations – needs to transcend national boundaries. Basic scientific research itself has, of course, always done this. But the task of agreeing the appropriate actions, much less implementing these actions at a national level, is less familiar and much more difficult. So, in each of the three examples, I will focus both on the problem itself and on the way the international scientific community is responding.

Climate change

The Industrial Revolution may be said to have begun in the 1780s, after James Watt developed his steam engine. At this time, ice-core records show that levels of carbon dioxide in the atmosphere were around 280 parts per million (ppm). Give or take 10 ppm, this had been their level for the past 6,000 years, since the beginning of the first cities. Over the wider sweep of Earth's history, levels of carbon dioxide, and the consequent climate, have seen huge swings. Even over *Homo sapiens*' tenancy of the planet, ice ages have come and gone. Noting that the past ten millennia have been unusually steady, some people have indeed argued that the beginnings of agriculture and the subsequent development of cities and civilisations is a consequence, not a coincidence.

After the 1780s, as industrialisation drove up the burning up of fossil fuels in the developed world, carbon dioxide levels rose. At first the rise was slow. It took about a century and a half to reach 315 ppm. Accelerating during the twentieth century, levels reached 330 ppm by the mid-1970s; 360 ppm by the 1990s; 380 ppm today. This change of magnitude by 20 ppm over only a decade has not been seen since the most recent ice age ended, ushering in the dawn of the Holocene epoch, around 10,000 years ago. And if current trends continue, by about 2050 atmospheric carbon dioxide levels will have reached more than 500 ppm, nearly double pre-industrial levels[10-12].

There are long time lags involved here, which are often not appreciated by those unfamiliar with physical systems. Once in the atmosphere, the characteristic "residence" time of a carbon dioxide molecule is a century. And the time taken for the oceans' expansion to come to equilibrium with a given level of greenhouse warming is several centuries. It is worth noting that the last time our planet experienced greenhouse gas levels as high as 500 ppm was some 20-40 million years ago, when sea-levels were around 100 m higher than today. The Dutch Nobelist, Paul Crutzen, has suggested that we should recognise that we are now entering a new geological epoch, the Anthropocene, which began around 1780, when industrialisation began to change the geochemical history of our planet.

Such increases in the concentrations of the greenhouse gases which blanket our planet will cause global warming, albeit with the time lags just noted. In their most recent report in 2001, the InterGovernmental Panel on Climate Change (IPCC) concluded that this warming would be in the range of 1.4 to 5.8^{0}C by 2100[10]. This would be the warmest period on earth for at least the last 100,000 years. Many people (especially, it would seem, some economists) find it hard to grasp the significance of such a seemingly small change, given that temperatures can differ from one day to the next by 10^{0}C. There is a huge difference between daily fluctuations, and global averages sustained year on year; the difference in average global temperature between today and the last ice-age[11] is only around 5^{0}C.

The impacts of global warming are many and serious: sea-level rise as mentioned above (which comes both from warmer water expanding, and also from ice melting at the poles); changes in availability of fresh water (in a world where human numbers already press hard on available supplies in many countries); and the increasing incidence of "extreme events" – floods, droughts, and hurricanes – the serious consequences of which are rising to levels which invite comparison with "weapons of mass destruction". In particular, recent studies, made before Katrina, suggest that increasing ocean surface temperature (the source of a hurricane's energy) will have little effect on the frequency of hurricanes, but strong effects on their severity[13]. The estimated damage inflicted by Katrina is equivalent to 1.7% of US GDP this year, and it is conceivable that the Gulf Coast of the US could be effectively uninhabitable by the end of the century.

The timescales for some important non-linear processes involved in climate change are uncertain. As the polar ice caps melt, the surface reflectivity is altered, causing more warming and faster melting; the timescale for the ice-cap to disappear entirely (a few decades?, a century?, longer?) is unclear[14]. As northern permafrost thaws, large amounts of methane gas are released, further increasing global warming (methane is a more efficient greenhouse gas than carbon dioxide). Nearer home, increased precipitation in the North Atlantic region, and increased fresh water run-off, will reduce the salinity of surface water.

Water will therefore be less dense and will not sink so readily. Such changes in marine salt balance have, in the past, modified the fluid dynamical processes which ultimately drive the Gulf Stream, turning it off on decadal time-scales. I should emphasise, however, that current thinking sees this as unlikely within the next century or more. But it is worth reflecting that the Gulf Stream, in effect, transports "free" heat towards the British Isles amounting to roughly 30,000 times the total

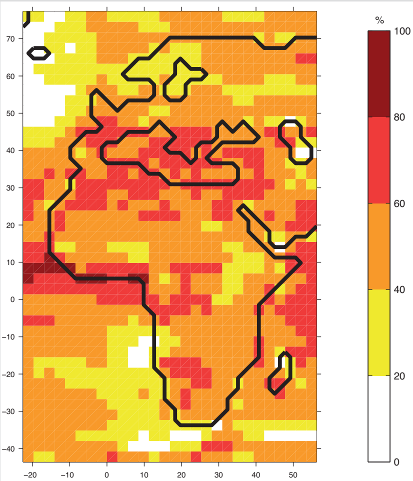


Figure 1: *Probability of extremely warm summer temperatures in 2081-2100 based on a multi-model multi-scenario ensemble, assuming each member of the ensemble to be equally likely. An extremely warm summer is one whose temperature lies in the 95th percentile category according to twentieth century control simulations[63].*

power generation capacity of the UK. These nonlinear and potentially catastrophic events are less well understood than is the direct warming caused by increased greenhouse gases. But their potential impacts are great, and should be included in risk assessments[15].

On a more directly biological note, some other effects of climate change are noted in two recent Royal Society reports. One[16] deals with the adverse impacts on marine biodiversity of the increase in acidity of the world's oceans, caused by absorbing carbon dioxide. The other[17] addresses the interplay between climate change and crop production, unhappily emphasising that "Africa is consistently predicted to be among the worst hit areas across a range of future climate change scenarios". This echoes the disconnect between the two central themes – Climate Change and Sustainable Development in Africa – of the UK's G8 Presidency. On the one hand, solemn promises were made to increase aid and support development in Africa, while on the other hand the lack of agreement on measures to curb greenhouse gas emissions means that increasing amounts of aid will be spent on tackling the consequences of climate change[18]. In this context, I emphasise the unprecedented step initiated by the Royal Society of producing two brief statements, on the science of climate change[19] and on the role of science and technology in promoting sustainable development in Africa[20], signed by the Science Academies of all the G8 countries (along with China, India and Brazil for the first, and the Network of African Science Academies for the second). The aim here was to clarify the consensus on climate change for the Summit Meeting under the UK Presidency of the G8 in July 2005.

So what should we be doing? One thing is very clear. The magnitude of the problem we face is such that there is no single answer, but rather a wide range of actions must be pursued. Broadly, I think these can be divided into four categories.

First, we can adapt to change: stop building on flood plains; start thinking more deliberately about coastal defences and flood protection, recognising that some areas should, in effect, be given up. In Holland, one quarter of which lies below sea-level, there are already plans for houses designed to float on seasonally flooded areas. Second, we can reduce inputs of carbon dioxide by reducing wasteful energy consumption. There are studies, for example, both in the US and in the UK, which demonstrate we can design housing which consumes roughly half current energy levels without significantly reducing living standards[21]. Third, we could capture some of the carbon dioxide emitted in burning fossil fuels, at the source, and sequester it (burying it on land or under the seabed). Fourth, we could move toward renewable sources of energy, which do not put greenhouse gases into the atmosphere. These include geothermal, wind, wave, and water energy; solar energy (from physics-based or biology-based devices); fission (currently generating 7% of all the world's energy, and – despite its problems – surely playing a necessary role in the medium-term); fusion (a realistic long-term possibility); biomass (assuming that the carbon dioxide you put into the atmosphere was carbon dioxide you took out when you grew the fuel). Some of these "renewables" are already being used, others are more futuristic. In total, they currently account for only 3% of the world's energy.

In particular, Pacala and Socolow[22] have presented a scheme of some fifteen "stabilisation wedges", each one of which would be sufficient to prevent a billion tonnes of carbon being emitted by around 2050. All fifteen wedges are based on proven technologies. They fall into three broad categories: energy demand, energy supply, and capture and sequestration of carbon dioxide emissions. They include such various actions as: more efficient buildings; better vehicle fuel use; carbon capture; wind power; solar power; nuclear power (at twice current levels); stopping tropical deforestation and planting new trees; biofuel (ethanol). Pacala and Socolow estimate that any seven of the fifteen, if implemented promptly and strenuously, could hold emissions at around 2010-2015 levels. Not one of these is easy or uncontroversial. But the scheme does illustrate that we could get there, if we put our minds to it, although certainly not with any single, simple technological fix.

Are we likely to do this?

We made a good start, with the setting up of the IPCC in 1988. The IPCC brings together the world's top scientists in disciplines related to climate change; some 1,250 authors and reviewers from 56 countries were involved in the preparation of its Third Assessment Report in 2001[10]. It deliberately seeks out dissenting voices, and is very careful to set out the degree of uncertainty in its findings. It has indeed created a lexicon of terminology for this purpose[23].

Following the first report of the IPCC in 1990, the Earth Summit in Rio de Janeiro in 1992 addressed the issue of climate change. The consequent UN Framework Convention on Climate Change (UNFCCC) has signatories from more than 180 countries, including President George H.W. Bush for the USA. It stated that the Parties to the Convention should take "Precautionary measures to anticipate, prevent or minimise the causes of climate change and mitigate its adverse effects. Where there are threats of irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures". All nations need to take part in such reductions in emissions of carbon dioxide. There are very large differences among the levels emitted by different countries. Measured in tonnes of carbon input to the atmosphere per person each year, the variation is from about 5.5 for the USA, 2.2 for Europe, 0.7 for China and 0.2 for India, down to lower levels for many developing countries. Table 1 amplifies this point. For the past several decades, the developed world has been moving – to different degrees in different countries – from coal to oil, gas and (to a small extent) renewables. The resulting lower carbon dioxide emissions per energy unit is known as "decarbonisation". With the rapid growth in energy use that is set to continue in industrialising countries like China and India, where supplies of coal are far more abundant than oil or gas, the next few decades are likely to see unhelpful "recarbonisation". Indeed, China, with its huge population, is expected to surpass the USA as the world's largest carbon emitter by around 2025.

Not surprisingly, there exists a climate change "denial lobby", funded to the tune of tens of millions of dollars by sectors of the hydrocarbon industry, and highly influential in some countries. This lobby has understandable similarities, in attitudes and tactics, to the tobacco lobby that continues to deny smoking causes lung cancer, or the curious lobby denying that HIV causes AIDS. Earlier, when some aspects of the science were less well understood, they denied the existence of evidence that human inputs of carbon dioxide and other greenhouse gases were causing global warming. More recently, there is acknowledgement of anthropogenic climate change, albeit expressed evasively, but accompanied by arguments that the effects are relatively insignificant, and/or that we should wait and see, and/or that technology will fix it anyway.

But make no mistake, climate change is undeniably real, caused by human activities, and has serious consequences. This has been reaffirmed, in the light of increasing scientific understanding, in the most recent report of the IPCC in 2001[10], by the US National Academy of Sciences (in its 2001 report), and most recently by the above-mentioned statement[19] from the Science Academies of all G8 countries, along with China, India and Brazil. This latter statement calls on the G8 nations to "Identify cost-effective steps that can be taken now to contribute to substantial and long-term reduction in net global greenhouse gas emission [and to] recognise that delayed action will increase the risk of adverse environmental effects and will likely incur a greater cost".

On 28 November 2005 the Eleventh Session of the Conference of the Parties to the UNFCCC will meet in Montreal. The UNFCCC does not identify targets for atmospheric concentrations, but rather specifies only that emissions should have been reduced to 1990 levels by 2000. The Kyoto Protocol extends this, setting targets for reducing emissions relative to 1990 levels by 2008-2012.

Both the UNFCCC and the Kyoto Protocol are political treaties, which explicitly state that the developed countries should lead the way in tackling climate change because they have been largely responsible for the rise in greenhouse gas concentrations so far.

	Poor	Transition	Rich
Population (billions) GDP (trillion ppp$)	4.1 11	1.2 11	0.8 23
Industrial energy (tw) Biomass energy (tw)	2.9 1.4	3.2 0.2	6.3 0.2
Fossil carbon input to atmosphere (billion tonnes C per year)	1.6	1.7	3.1

Table 1[60]

In particular, it is likely there will be an argument in Montreal over whether new targets for reducing emissions should be set, beyond the first period of the Kyoto Protocol. The US prevented a discussion of new targets at the previous meeting, in December 2004.

The Montreal meeting could be constructive if there at least emerged agreement to initiate a study of target levels for atmospheric concentrations, as a basis for discussing appropriate plans of action. More difficult will be that countries must recognise the need to sever the link between economic growth and increasing emissions of greenhouse gases. No country, including the UK and US, has yet managed to achieve this, mainly because growth currently means increased use of energy generated from fossil fuels. Appropriately constructed economic instruments, such as a carbon tax, could help motivate a reappraisal of this perverse message. Ultimately, we need to acknowledge that the increasing incidence and/or severity of "extreme events" (floods, heatwaves, droughts, hurricanes, and the like) is associated with climate change, and the consequent costs to national economies seem likely to exceed those estimated for implementing, for example, Pacala and Socolow's seven wedges.

Initiating such a study of target levels in Montreal should not diminish the pressure for all countries to start cutting emissions now. Small actions now will, given the nature of the non-linear dynamical processes at work, be more important than big actions later. The UK already seems likely to miss its target for the Kyoto Protocol, because emissions have risen for the past two years, owing to the UK not getting to grips with the difficult questions of meeting demand for electricity and transport without burning more and more fossil fuels. By the same token, emissions of greenhouse gases by the US are currently 20% higher than in 1990, compared with the target assigned to it in Kyoto of a cut of 7%. President George W. Bush's failure to follow through on the commitments his father made on behalf of the US is underlined by his failure even to mention climate change, global warming or greenhouse gases in his 2,700-word speech when welcoming the new US Energy Act in August 2005, just weeks after signing the Gleneagles G8 communiqué.

In short, we have here a classic example of the problem or paradox of co-operation (also known as the Prisoner's Dilemma or occasionally the Tragedy of the Commons) referred to at the outset: the science tells us clearly that we need to act now to reduce inputs of greenhouse gases; but unless all countries act (in equitable proportions), the virtuous will be economically disadvantaged whilst all suffer the consequences of the sinners' inaction. In this sense, the climate change disaster which looms this century is an appallingly large-scale experiment in the social sciences.

If this experiment is to end in success for humankind, then it is essential that progress be made at the Montreal meeting. We need countries to initiate a study into the consequences of stabilizing greenhouse gas concentrations at, below, or above twice pre-industrial levels, so that the international community can assess the potential costs of their actions or lack of them. Such an analysis could focus the minds of political leaders, currently worried more about the costs to them of acting now than they are by the consequences for the planet of acting too little, too late.

Biological diversity

Seen through a wider-angle lens, the impending diminution of the Earth's diversity of plant and animal species could be an even greater threat than climate change. Unfortunately, analysis of the causes and consequences of accelerating extinction rates is impeded by the rudimentary state of our knowledge, which in turn – as discussed further below – derives more from past intellectual fashions than dispassionate assessment of scientific priorities.

Currently around 1.5 to 1.6 million distinct species of plants and eukaryotic animals have been named and recorded[24, 25]. Even this number – analogous to the number of books in the British Library, which is precisely known – is uncertain to within around 10%, because the majority of species are invertebrate animals of one kind or another, for most of which the records are still on file cards in separate museums and other institutions. Lacking a synoptic database, it is hard to sort out problems with synonyms[26] (the same species being separately identified and differently named in two or more places). Currently, new species are being identified at the rate of around 13,000 a year, while at the same time earlier synonyms are being resolved at around 3,000 each year, for a net addition of roughly 10,000 species per year[24].

So much for what is known. But how many species may there be in total on Earth today? Recent estimates lie in the range 5 to 15 million[24, 25]. Lower numbers, and also much higher ones, also have their advocates. Even if we take a low estimate of 3 million still to be identified, at the current rates just noted the job would take 300 years. Organising better databases, and using molecular information about newly-discovered species' genomes ("bar coding life"), promises to speed up this distressingly slow task[27]. Even so, the craft of collecting material in the field will remain a seriously rate-limiting step.

If we do not know how many species have been identified (much less their functional roles in ecosystems) to within 10%, nor the overall species total to within an order-of-magnitude, we clearly cannot say much about how many species are likely to become extinct this century. We can note that the IUCN Red Data Books in 2004, using specific and sensible criteria, estimate 20% of recorded mammal species are threatened with extinction, and likewise 12% of birds, 4% of reptiles, 31% of amphibians, 3% of fish, and 31% of the 980 known species of gymnosperms[28]. However, when these figures are re-expressed in terms of the number of species whose status has been evaluated (as distinct from dividing the number known to be threatened by the total number known – however slightly – to science), the corresponding numbers are 23, 12, 61, 31, 26, 34% respectively; this says a lot about how much attention reptiles and fish have received. The corresponding figures for the majority of plant species, dicots and monocots, are respectively 4 and 1% of those known, versus 74 and 68% of those evaluated. Most telling are the two numbers for the most numerous group, insects: 0.06% of all known species are threatened, versus 73% of those actually evaluated. The same pattern holds true for other invertebrate groups. For these small things, which arguably run the world, we know too little to make any rough estimate of the proportions that have either become extinct, or are threatened with it.

Image: *DNA barcoding of insects: a sampler of ant biodiversity[64]*

Perhaps surprisingly, we can nevertheless say some relatively precise things about current and likely future **rates** of extinction in relation to the average rates seen over the roughly 550 million year sweep of the fossil record[29]. For bird and mammal species (a total of approximately 14,000), there has been an average of about one certified extinction per year over the past century. This is a very conservative estimate of the true extinction rate, because many species receive little attention even in this unusually well-studied group. Such a rate, if continued, translates into an average "species' life expectancy" of the order of 10,000 years. By contrast, the average life expectancy – from origination to extinction – of a species in the fossil record lies in the general range 1 million to 10 million years, albeit with great variation both within and among groups.

So, if birds and mammals are typical (and there is no good reason to assume they are not), extinction rates in the twentieth century were higher, by a factor of 100 to 1,000, than the fossil record's average background rates. And four different lines of argument suggest a further tenfold speeding up over the coming century. Such an acceleration in extinction rates is of the magnitude which characterised the Big Five mass extinction events in the fossil record. These Big Five are used to mark changes from one geological epoch to the next. Here, separate from the climate change argument, is another good reason to recognise the advent of Crutzen's Anthropocene. Note, however, the crucial difference between the Sixth Wave of mass extinction and the previous Big Five: the earlier extinctions stemmed from external environmental events; the sixth, set to unfold over the next several centuries (seemingly long to us, but a blink of the eye in geological terms), derives directly from human impacts.

The main causes of extinction are habitat loss, overexploitation, and introduction of alien species[30]. Often two, or all three, combine. An increasing number of recent studies show, moreover, that the effects of climate change are compounding these more direct effects of human activities[31].

At the World Summit on Sustainable Development in Johannesburg in 2002, building on the 1992 UN Conference on Environment and Development in Rio de Janeiro, the 188 parties to the Convention on Biological Diversity agreed targets for achieving "a significant reduction in the current rate of biodiversity loss by 2010". This commitment includes all of the world's nation states except seven; the curious "coalition of the unwilling" is Andorra, Brunei, Somalia, Timor-Leste, Iraq, the Vatican, and the USA. The EU has set the challenging target of actually halting biodiversity loss by 2010. Following the Rio Conference, the UK launched the Darwin Initiative, which has helped developing countries produce their "Biodiversity Action Plans".

Conservation of biological diversity ineluctably requires that the world be seen as one place, with scientific activities co-ordinated across national boundaries. I think the most important such co-ordinated activity has been the UN-sponsored Millennium Ecosystem Assessment[32] (MEA), to which the Royal Society is an affiliated organisation. The MEA published its extensive report earlier this year. The actual launch was simultaneous at several locations (with the Royal Society being the flagship site in Europe), and received extensive media coverage almost everywhere except, to my mind surprisingly, the USA. The MEA report integrated ecological studies with economic and social considerations, and concluded that approximately 60% of the ecosystem services that support life on Earth – such as fresh water, fisheries, air and water regulation, pollinators for crops, along with the regulation of regional climate, pests, and certain kinds of natural hazards – are being degraded and/or used unsustainably. These ecosystem services are not counted in conventional economic measures of global GDP, but necessarily rough estimates suggest their monetary value (at around $30 – 40 trillion in1996) is of the same order as the economists' GDP[33].

These battles about sustainability are not all being played out in distant places. Despite some encouraging recent improvements, roughly 1% of Britain's Sites of Special Scientific Interest (SSSIs), which still do not receive statutory protection, suffer serious damage each year. This invites comparison with rates of tropical deforestation.

Fisheries are a particularly telling example of the gulf that yawns between clearly identifying a problem and taking effective action. We currently take, in the form of fisheries of one kind or another, roughly 8% of global aquatic primary productivity, and roughly 30% in the most productive areas of fresh water and oceanic upwelling[34]. It is therefore not surprising that the MEA reports at least one quarter of global marine fish stocks are over-harvested. The quantity of fish caught by humans increased up to the 1980s, but is now in decline because of the shortage of stocks. In some areas of the sea, the total weight of fish available to be captured is less than one tenth of that caught before the onset of industrial fishing[35]. The collapse of the Grand Banks fisheries in the Northwest Atlantic, once of legendary productivity, is a striking example.

In 2003 and 2004, the International Council for the Exploration of the Sea (ICES), which co-ordinates and promotes marine research in the North Atlantic, recommended that there should be zero catches of cod in the North Sea, Irish Sea and west of Scotland. It warned that North Sea cod has been fished down to the lowest level ever seen. Nevertheless, when the national fishing quotas for 2005 were agreed at the end of last year, the European Commission, under short-sighted political pressures and in the teeth of the evidence, denied proposals to close these depleted cod fishing grounds.

The fisheries scientist Daniel Pauly has notably remarked[36] that the interplay between fisheries science (which, although there is still much to learn, would be adequate to manage fisheries sustainably) and fisheries management resembles a splendid and well-equipped hospital, where patients' problems are diagnosed accurately, but where nobody receives treatment!

Overexploitation of fisheries, local and global, is just one of many examples where scientific understanding points clearly to the unsustainability of present practices, yet where human institutions seem incapable of looking beyond today. Of course, for fisheries or other overexploited biological resources, those who are focused on the immediate gain will always depict themselves as motivated by uncertainties – real or imagined – in the science. Discussing that past microcosm of today's global dilemmas, Jared Diamond[37] has asked what the Easter Islanders said as they cut down the last trees, dooming themselves to a canoeless future and consequent extinction. Did they say "it's jobs not trees" or "we need more research" or "we'll wait until the others stop", or what? Probably they lacked clear understanding of the consequences of their actions. We have no such excuse.

Plagues and peoples

While we were hunter-gatherers, the human population probably never exceeded 20 million. Once we began to cultivate crops, around 10,000 years ago, larger aggregates became possible, and human populations grew. Estimates suggest, however, that the first 5,000 years saw faster population growth than the second 5,000 (until the beginning of the scientific-industrial revolution a few centuries ago). This relative slowing was probably caused by directly transmissible infectious diseases, which need large populations if they are to be maintained (measles, for example, cannot persist in a population smaller than 200,000 or so). John Reader[38] summarises it well: "Bacterial and viral diseases are the price humanity has paid to live in large and densely populated cities. Virtually all the familiar infectious diseases have evolved only since the advent of agriculture, permanent settlement and the growth of cities. Most were transferred to humans from animals – especially domestic animals. Measles, for instance, is akin to rinderpest in cattle; influenza came from pigs; smallpox is related to cowpox. Humans share 296 diseases with domestic animals."

Recent recorded history testifies to the impact of past plagues[39, 40]. The Black Death, *Yersinia pestis*, killed one third, or maybe even half, of the population of Western Europe in the fourteenth century. Shortly after the Royal Society was founded, Plague in 1665 killed an estimated 14%, or one in seven, of the population of London[41].

As recently as Victorian times, half the children born in Liverpool in 1860 did not survive their first five years, carried off by infections in conjunction with poor living conditions. However, throughout the 1800s and into the early 1900s, deaths from infectious diseases – scarlet fever, diphtheria, TB, measles, and others – declined in most developed countries, to comparatively low levels in the 1930s, before the advent of antibiotics or most vaccines[40]. This decline probably resulted from both better hygiene and better nutrition. The causes, however, remain contentious (McKeown[42] suggested "washing hands is as effective as wringing them"; he attributed it all to nutrition). Ultimately, the causes of this decline remain ill-understood, and would in my opinion repay closer examination. Once antibiotics and mass vaccination became available, however, it seemed to many in the developed world that science had triumphed over infectious diseases. In 1967, the US Surgeon General introduced his annual report by writing: "The time has come to close the book on infectious diseases".

Whatever its status within the OECD, this statement was, and remains, inapplicable to the developing world. This being remarked, it should also be noted that the developing world today bears no comparison with the infection-inflicted horrors of 1860 Liverpool. Around the globe last year, 130 million children were born, of whom 10 million, or almost 8%, will not survive their first five years. This is lamentable and avoidable. But advances in understanding the transmission and treatment of childhood infections – often simple measures like rehydration and electrolytes for infant diarrhoeas and for cholera – invalidate comparisons with mid-Victorian mortality rates.

It could, however, be argued that the benefits that have accrued to health in the developing world are almost an epiphenomenon of what Tom Lehrer memorably called "diseases of the rich". Table 2 shows a recent analysis of the proportion of papers published in the four leading medical journals that deal with problems of the developing world. The overall average is around one paper in seven, and a large number of these are on HIV/AIDS, a problem shared by developed and developing countries. Research on developing countries' "orphan diseases" is increasing, owing largely to the "Grand Challenges in Global Health" launched by the Bill and Melinda Gates Foundation, but from a regrettably low base.

Events of the past two decades have underlined the foolishness of the 1967 Surgeon General's boast: HIV/AIDS; SARS; avian flu. Like humankind's earlier diseases, all three of these come from associations with non-human animals, and more particularly from the growing bushmeat trade for the first two. This once was a traditional and local practice, but is rapidly becoming a global industry[43]. I am among those who believe it likely that other new plagues will emerge from it.

Taking these three in reverse order, recent studies suggest we may be able to avoid a repeat of the lethal 1918 flu pandemic, provided we have efficient surveillance (especially in South East Asia), adequate stocks of Oseltamivir ("Tamiflu") for targeted antiviral prophylaxis, and effective use of them[44, 45]. The 1918 pandemic killed an estimated 20 to 50 million people. But the global population then was less than 2 billion, with only one quarter urban, and the relatively smaller number of people crossing oceans did so in

Journal	Proportion of Articles	
	Jan 2002	Jan 2003
USA: New England Journal of Medicine	7% (7/97)	3% (3/118)
Journal of the American Medical Association	7% (12/180)	4% (5/138)
UK: Lancet	21% (50/234)	23% (52/227)
BMJ (British Medical Journal)	24% (66/273)	18% (44/242)
Overall:[62]	15%	12%

Table 2[61]
Proportion of papers in four leading medical journals which relate (defined in accordance with the UN Global Forum on Health Research) to developing countries.

ships. Today's threatened pandemic looms over a more crowded world of 6.5 billion, half urban, constantly and rapidly moving around. Our scientific understanding is very much greater, but our circumstances are inherently more difficult[46].

SARS could be seen as a successful rehearsal for H5N1 Avian Flu[47]. Two factors are central to plans for controlling an epidemic. One is the infection's reproductive number, R_0, which quantifies its transmissibility; R_0 is defined as the average number of secondary cases generated by a typical primary case in an entirely susceptible population[40]. Epidemics can arise if R_0 exceeds one, and not otherwise. Control strategies aim to reduce R_0 below one, by effectively removing a proportion, $1 – (1/ R_0)$, of the susceptible population, by vaccination or other prophylactic measures. The other factor is the time interval between an infected individual becoming infectious and becoming symptomatic (as distinct from the longer interval during which the individual is infectious); obviously things will be easier the shorter this time interval is. In the case of SARS we were lucky, in that R_0 was around 2-3, which is smaller than is typically the case for influenza, or for most other directly transmitted infections, and the time interval between infectiousness and symptoms was significantly shorter than is the case for influenza[48].

In contrast, the latest statistics on the continuing spread of the Human Immunodeficiency Virus (HIV) across the world and the global AIDS pandemic make depressing reading. The UN estimates that around 40 million people are living with HIV, with an estimated 2.3 million of them being children under the age of 15. In 2004, 3.1 million died of AIDS, and an estimated 4.9 million were newly infected with HIV. These statistics may be underestimates, because there are still significant problems with reporting in some countries.

In 2001, the UN adopted a Declaration of Commitment on HIV/AIDS. This identified prevention as the mainstay of the global response. However, a report for the UN Secretary General in June 2005 concluded that the pace of the expansion of the epidemic is accelerating, and stated: "Although proven strategies exist to prevent new HIV infections, essential prevention strategies reach only a fraction of those who need them".

This statement is a tactful way of saying that the dissemination and adoption of successful prevention strategies is being seriously hindered by arguments over the role that contraception in the form of condoms should play. This controversy has nothing to do with a scientific assessment of the effectiveness of condoms in preventing the transmission of HIV, but rather derives from religious beliefs against the use of contraception. The Vatican in particular promotes abstinence outside marriage, and condemns condom use. This disapproval, for all its putative high-mindedness, simply is not an effective strategy for preventing dissemination of HIV, not least because unprotected sex with an infected individual is high risk regardless of whether the act is intended for procreation or recreation. With added support from fundamentalist groups, these arguments have the effect that aid from the United States for tackling HIV/AIDS seems usually to be tied to promoting abstinence and condemning condom use.

A recent review by the US National Institutes for Health found that, when used consistently, condoms reduce the probability of HIV transmission per sex act by as much as 95%, and reduce the annual HIV incidence between couples of different HIV status by 90-95%. There is also evidence that promoting abstinence and fidelity along with condom use in Uganda has helped reduce rates of HIV infection there. In short, a significant body of research has shown that condom use is the most effective way of preventing HIV transmission among sexually active individuals.

Notwithstanding all this, condom use in areas of the world with the highest incidence of HIV/AIDS remains low, with representative surveys of women in 13 African countries finding that fewer than 7% report condom use in the most recent sex act with their regular partner. The Vatican has, moreover, expressed its belief in the immorality of condom use by seeking to undermine efforts to promote their use as an effective way of preventing HIV transmission. On 1 December 2003, the Vatican issued a document[49] on "Family Values versus Safe Sex" as a "reflection" by Cardinal Lopez Trujillo: "Condoms may even be one of the main reasons for the spread of HIV/AIDS. Apart from the possibility of condoms being faulty or wrongly used they contribute to the breaking down of self-control and mutual respect". This document also claimed that condoms have, on average "a 10-15% inefficacy" and went on to say: "therefore, even at a 'technical' level of efficacy, one should question the scientific seriousness and the consequent professional seriousness of the condom campaign". There have also been repeated assertions that the HIV virus can move through the condom membrane, which simply is not the case.

I have dwelt on this campaign against condom use by individuals and institutions motivated by dogma, because it provides another example where faith and belief not only override evidence, but also lead to deliberate misrepresentation of the facts (presumably in the service of a higher good). In this sense, it is a companion – both in spirit and in tactical detail – to the campaigns denying the reality of climate change or the seriousness of diminishing biodiversity.

The nature of scientific knowledge

The campaigns waged by those whose belief systems or commercial interests impel them to deny, or even misrepresent, the scientific facts are helped by the widespread public misapprehension that science essentially always gives unambiguous and definite answers. This misapprehension is both understandable and unfortunate.

Understandable, because the science taught in primary and secondary school, and also in much tertiary education, is about things we really understand very fully. This is, after all, the easiest way to organise curricula, and to set exam papers. Even more, the answers to "science" questions on TV quiz shows – University Challenge, Mastermind, The Weakest Link, and so on – cannot permit ambiguity and debate; here scientific understanding is misleadingly trivialised as definitions or nomenclature.

Unfortunate, because although much of science deals with things that are indeed extremely well understood, many of the topics that engage public attention lie at, or beyond, the frontiers of what is currently known. More generally, the landscape of scientific understanding is complex. At the ever-expanding frontiers, different ideas and opinions contend; the terrain is bumpy. But there are huge swathes of territory behind the frontier where evidence-based understanding has been securely achieved. For example, the Laws of Thermodynamics tell us assuredly that perpetual motion machines are impossible. In astonishing defiance of intuition, we now know that mass and energy can be interchanged, according to science's most celebrated formula, $E = mc^2$.

When AIDS was first recognised in the early-to-middle 1980s, various possible explanations contended; the landscape was one of many hillocks. Observation and experiment, however, fairly rapidly identified the virus HIV as the causative agent (helped by earlier "blue-skies" research on retroviruses).

Although we as yet lack any agreed explanation for why there is so long and variable an interval between an individual becoming infected with HIV and coming down with AIDS, we do have an understanding – at the detailed molecular level – of how individual HIV viruses interact with individual immune system cells, and on this basis have been able to produce antiretroviral agents which keep HIV-infected people alive. By the same token, suggestions that the release of carbon dioxide by burning fossil fuel would cause greenhouse warming were made many decades ago. They were, however, beset with many uncertainties. The past two decades have seen great advances in acquiring observational and experimental data of many different kinds, and consequently in increasingly detailed computer models. But as the sciences of HIV/AIDS and of climate change have moved from their past positions at or beyond the frontiers of scientific understanding, into *terra cognita* which can provide a secure basis for effective action, there remain those who seek deliberately to confuse yesterday's uncertainty with today's fact-based understanding.

In this context, the Royal Society is pleased that the teaching of science at GCSE level will, from September 2006, concentrate more on improving young people's understanding of how science works, rather than on rote memorisation of uncontextualized definitions. That is, it will emphasise: collection, analysis and interpretation of data; the use of evidence to test ideas and develop theories; how explanations of many phenomena can be developed using scientific theories, models and ideas; and how there are some questions that science cannot currently answer, and even some questions that science cannot address. Young people should learn to have trust in science even when there may be uncertainty, scepticism in the face of propaganda purporting to be knowledge, and confidence that what we ask them all to learn is of value in their everyday lives.

More generally, we must of course recognise there is always a case for hearing alternative, even maverick, views. But we need to give sensible calibration to them. I could assemble half a dozen people (including one Nobel Laureate) who deny that HIV causes AIDS, and put them up against an equal number of researchers in this area. But unless I simultaneously gave some sense that the first six are a kind of travelling road-show, representing little beyond themselves, while the latter six could be chosen from among a hundred-thousand or more researchers in the field, I would, in effect, be misleading the public[50]. The intention of "balance" is admittedly admirable, but this problem of wildly disparate "sides" being presented as if they were two evenly balanced sporting teams is endemic to radio, TV, print media, and even occasional Parliamentary Select

Committees. England playing Australia is one thing; England playing the local village team is something else entirely.

These problems of effectively communicating what is known, and what is not, are further complicated, as noted above, when what really is at issue is a belief system masquerading as scientific scepticism, for example when Darwinian Evolution is questioned by Creationists disguised as proponents of the "alternative science of Intelligent Design" (ID). Broadly similar problems arise when a newspaper adopts an *ex cathedra* editorial position, as for example in the editorial line adopted by The Sunday Times in the 1990s that HIV does not cause AIDS.

Yet another kind of difficulty[51] can be posed by those who emphasise "the constructed and value-laden character of scientific knowledge". Taken to extremes, this can lead to the view that scientific knowledge is no more than a "social construct", rather than statements about the external world, which in reality is (in Max Planck's words[52]) "independent of our senses [with its laws] not invented by humans".

My personal belief is that important aspects of science, in the widest sense, are indeed laden with values; but we need carefully to parse out which aspects are, and which not. The inverse square law of gravity, for example, **is** value free. So are Maxwell's equations. These are plain facts, and any pretence to the contrary is silly. This is what Planck was talking about. The agenda of science, on the other hand, usually does reflect the values of particular times and places, although usually in implicit and unconscious ways. The fact that the inverse square law, itself based on centuries of observation of the motion of planetary bodies, came a full century before Linnaeus began the task of codifying the diversity of plants and animals that share our planet testifies eloquently to the vagaries of intellectual fashion that have shaped science's agenda. And the applications of our scientific knowledge bear the signature of social and political pressures even more strongly. For instance, recall Table 2, with its relative neglect of "unprofitable diseases". Or note that, whereas the earlier Green Revolution was largely born of public and charity money (especially the Rockefeller Foundation) and had an agenda oriented to consumers in the developing world, the first wave of applications of GM technology to crops was with private-sector money, and consequently directed mainly to agribusiness rather than nutritional deficiencies in the developing world.

In everything I have said above there is the implicit, but hugely important, assumption that the scientific community has an obligation to explain itself – its agenda, its achievements, and their potential applications – to the public. This means individual scientists engaging more with wider society, explaining

what they do and why, and responding through dialogue and debate to the interests, concerns and aspirations of the public. Such engagement is not always easy, in part because it often requires simplifying things (usually painful to researchers for whom the details can be entrancing), and must always avoid distortion. This dialogue between researchers and the general public – or, more accurately, the many and varied "publics" – has in recent years been seen as an integral part of the scientific process. The UK has, I believe, been a leader in this, partly as the result of unfortunate earlier experiences (BSE in particular). The Royal Society hopes that, through its "Science in Society" programme and other activities, it has been creative in its exploration of such engagement.

Ultimately, as science advances our understanding of the external world, it offers us opportunities to improve life for all. However, as we increasingly come to recognise the unintended adverse consequences of well-intentioned actions (as seen above for climate change and for biodiversity loss), it behoves us to think more carefully about which doors to open and which to leave closed. In this task, the job of science is to frame the debate clearly, making plain the possible benefits and costs – and the concomitant uncertainty. And making clear that cloud cuckooland is not a feasible choice. But when it comes to acting out the democratic drama of choice on the stage thus set, science has no special voice; the drama of choice is about values and beliefs, about what kind of world we want.

Such choices, against a background framed by scientific facts and uncertainties, is hard enough. As emphasised earlier, it is more difficult when fundamentalist or other belief systems seek to blur the distinction between constraining facts and democratic decisions. We should keep in mind the cautionary tale of Indiana State, where in 1897 its Lower House voted to define the transcendental number π (the ratio of a circle's circumference to its diameter) to be exactly 3.2 to make things easier for the construction industry; their Upper House saved embarrassment by vetoing the bill.

Twilight for the Enlightenment?

Previous Anniversary Addresses have focused on the Royal Society's activities in relation to Science in Society (2002), how best to manage the research enterprise ("managing creativity", 2003) and the growth of international co-operation among the world's Science Academies (2004). In each case, I tried also to give a sketchy annual report on the work of the Royal Society itself. This 2005 Anniversary Address is obviously an indulgently personal one, setting out some of my fears and hopes for our global future.

I end this valedictory Address much as I began my first one, by again reminding us that the Royal Society was born of the Enlightenment. Everything we do embodies that spirit: a fact-based, questioning, analytic approach to understanding the world and humankind's place in it. *Nullius in Verba*.

Many people and institutions have always found such questioning, attended often by unavoidable uncertainties, less comfortable than the authoritarian certitudes of dogma or revelation. But the values of the Enlightenment have on balance – often one step backward for two steps forward – made the world a better place. They have, in the words of that splendidly archetypal document of the Enlightenment, the American Constitution, enhanced life, liberty, and the pursuit of happiness.

Today, however, fundamentalist forces are again on the march, West and East. Surveying this phenomenon, Debora MacKenzie[53] has suggested that – in remarkably similar ways across countries and cultures – many people are scandalised by "pluralism and tolerance of other faiths, non-traditional gender roles and sexual behaviour, reliance on human reason rather than divine revelation, and democracy, which grants power to people rather than God." She adds that in the US evangelical Christians have successfully fostered a belief that science is anti-religious, and that a balance must be restored, citing a survey which found 37% of Americans (many of them not evangelicals) wanted Creationism taught in schools. Fundamentalist Islam offers a similar threat to science according to Ziauddin Sardar[54], who notes that a rise in literalist religious thinking in the Islamic world in the 1990s seriously damaged science there, seeing the Koran as the font of all knowledge.

In the US, the aim of a growing network of fundamentalist foundations and lobby groups reaches well beyond "equal time" for creationism, or its disguised variant "intelligent design", in the science classroom. Rather, the ultimate aim is the overthrow of "scientific materialism", in all its manifestations. One major planning document[55] from the movement's Discovery Institute tells us that "Design theory promises to reverse the stifling dominance of the materialist world view, and to replace it with a science consonant with Christian and theistic convictions". George Gilder, a senior fellow at the Discovery Institute, has indicated[55] that this new, faith-based science will rid us of the "chimeras of popular science", which turn out to be ideas such as global warming, pollution problems, and ozone depletion.

In a powerful speech on receiving Harvard Medical School's Global Environmental Citizen Award, the veteran newscaster Bill Moyers[56] noted one extreme form of US fundamentalism, the fantastic theology which sees the End of Days and the advent of "The Rapture" – when the saved ascend to eternal grace, and the rest of us writhe in damnation – as happening any day now, and certainly within the next 40 years. If you believe this, you clearly do not worry about 2050. The adherents of this lunacy comprise an estimated 20-40% of Biblical literalists (a bit paradoxical, because Rapture is nowhere mentioned in it), which means well over ten million. More generally, Moyers concludes "the delusional is no longer marginal but has come in from the fringe to influence the seats of power. We are witnessing today a coupling of ideology and theology that threatens our ability to meet the growing ecological crises. Theology asserts propositions that need not be proven true, while ideologues hold stoutly to a world view despite being contradicted by what is generally accepted as reality. The combination can make it impossible for a democracy to fashion real-world solutions to otherwise intractable challenges."

In the above discussions of climate change, biodiversity, and HIV/AIDS, I gave examples where ideology appeared to triumph over scientific facts. Moyers's view of "the delusional [sitting] in the seats of power" is supported by Tristram Hunt's[57] report that "Neil Lane, former Science Advisor to President Clinton, has spoken of 'a pattern of abuse of science' in policy making within today's White House. What they don't like, they suppress and distort. Official publications on the science of climate change have been brazenly replaced with drafts from utility lobbyists." Or see Donald Kennedy's editorial in *Science* which provided the subheading for this section[3, 58]: "When the religious/political convergence leads to managing the nation's research agenda, its foreign assistance programs, or the high-school curriculum, that marks a really important change in our national life."

In the Islamic world, we also see enlightenment threatened by extremist sects, whose acts evoke the brutal practices which gave us the word Assassin. A sense of the complexities here is given by Scott Atran[59]: "People attribute Islamic fundamentalism to Islam, but I think it has as much – or more – to do with Christian fundamentalism. You'll find no apocalyptic visions in Islam; it comes from the *Book of Revelation*." Whatever the root causes of the rise in, and confrontations between, fundamentalist sects West and East, the bleak world of Orwell's 1984 seems a real threat, a few decades later than predicted.

The really sad thing is that none of these fundamentalist beliefs are grounded on, or representative of, the mainstream religions they profess to serve. Fundamentalist

Christianity is widely considered as irrelevant to modern theology as it is to modern science. The extremist views and acts of fundamentalist Islam find little sanction in the Koran. Karen Armstrong suggests that "to fight the secular enemy, fundamentalists reduce complex faiths to streamlined ideologies and, above all, try to recast old mythical tales as modern, literal truths." In so doing, they tend to lose the compassion that is the mark of mature religious beliefs.

More generally, many of the "moral dilemmas" that are said to arise from scientific advances – such as stem cell research – do not in fact arise from any conflict between science and ethical universals. Rather, as Kennedy emphasises[3], they arise "from a particular belief about what constitutes a human life: a belief held by certain religions but not by others". Given that public opinion polls in the US, as in the UK, indicate roughly two to one support for stem cell research, legislation based on the religious beliefs of influential minority groups can bring church and state uncomfortably close.

Ahead of us lie dangerous times. There are serious problems that derive from the realities of the external world: climate change, loss of biological diversity, new and re-emerging diseases, and more. Many of these threats are not immediate, yet their nonlinear character is such that we need to be acting today. And we have no evolutionary experience of acting on behalf of a distant future; we even lack basic understanding of important aspects of our own institutions and societies.

Sadly, for many, the response is to retreat from complexity and difficulty by embracing the darkness of fundamentalist unreason. The Enlightenment's core values, which lie at the heart of the Royal Society – free, open, unprejudiced, uninhibited questioning and enquiry; individual liberty; separation of church and state – are under serious threat from resurgent fundamentalism, West and East. Our forceful and effective presence on the national and international stage is more important today than at any time in the Royal Society's 345-year history[65].

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36. This memorable analogy was offered by Daniel Pauly at the 1984 Dahlem Conference on *Exploitation of Marine Communities*. Unfortunately, Pauly's observation is as true today, twenty years on, as it was then.

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43. See the paper by D. Bell in note 47 and 'Origins of HIV and the AIDS epidemic', *Phil. Trans. R. Soc B* (Theme Issue, 29 June 2001), **356**, no. 1410, pp.777-977.

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50. Here is one specific example. In 2004 Naomi Oreskes studied the 900+ articles on climate change published in refereed journals between 1993 and 2003 (quoted in Ref. 12, p. 61) Three-quarters endorsed the view that anthropogenic emissions were at least partly responsible for the observed warming of the past 50 years. The remaining quarter, which mainly dealt with methodology or climate history as such, did not discuss current conditions. Not one single paper presented evidence or argued against anthropogenic warming being a fact. This is, to put it gently, not the impression conveyed by Fox News or our own Daily Mail.

51. Jasanoff, S., *Designs on Nature: Science and Democracy in Europe and the United States*. (Princeton University Press, 2005). See also the review by Cantley, M. 2005 *Nature* **437**, 193–194.

52. Quoted by J. M. Thomas in his address at Max Perutz's Memorial Service in Cambridge, 21 Sept 2002.

53. MacKenzie, D., End of the Enlightenment. *New Scientist* 8 Oct 2005, pp. 40–43.

54. The quotes by Armstrong and by Sardar are from Ref. 53.

55. Holderness, M., Enemy at the gates. *New Scientist*, 8 Oct 2005, pp. 47-49.

56. Moyers, B., Welcome to Doomsday. *New York Review of Books* **52(5)**, 8–10 (2005).

57. Hunt, T., *The Guardian*, 22 March 2005.

58. Particularly disconcerting is the account of Ron Suskind's meeting with a "senior advisor to Bush", who is quoted as saying "what we call the reality-based community … believe that solutions emerge from judicious study of discernable reality, [but] that's not the way the world really works anymore. We're an empire now, and when we act, we create out own reality." From *The New York Times*, 17 Oct 2004.

59. This quote by Atran is from Brooks, M., Meeting of minds. *New Scientist*, 8 Oct 2005, pp. 44-46.

60. From Table 3 in Holdren, J., Environmental Change and the human condition. *Bull. Amer. Acad. Arts & Sci.*, Fall 2003, pp. 24-31.

61. Raja, A. J. & Singer, P. A., *Br. Med. J.*, **329**, 1429–1430 (2004). Available at www.pubmedcentral.15604171.

62. These overall percentages are unweighted averages over the four journals.

63. After Fig. 8 in Palmer, T.N. et al, Probabilistic prediction of climate using multi-model ensembles, *Phil. Trans. R. Soc. B*, (in press).

64. Images created by April Nobile, Antweb.org; courtesy of Brian Fisher.

65. I am grateful to Iain Finlayson, Rachel Quinn, Bob Ward and others for help with this speech/document. In particular, I thank Chris Bond and Carol Gray, my PAs in Oxford and London respectively, for their assistance.

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